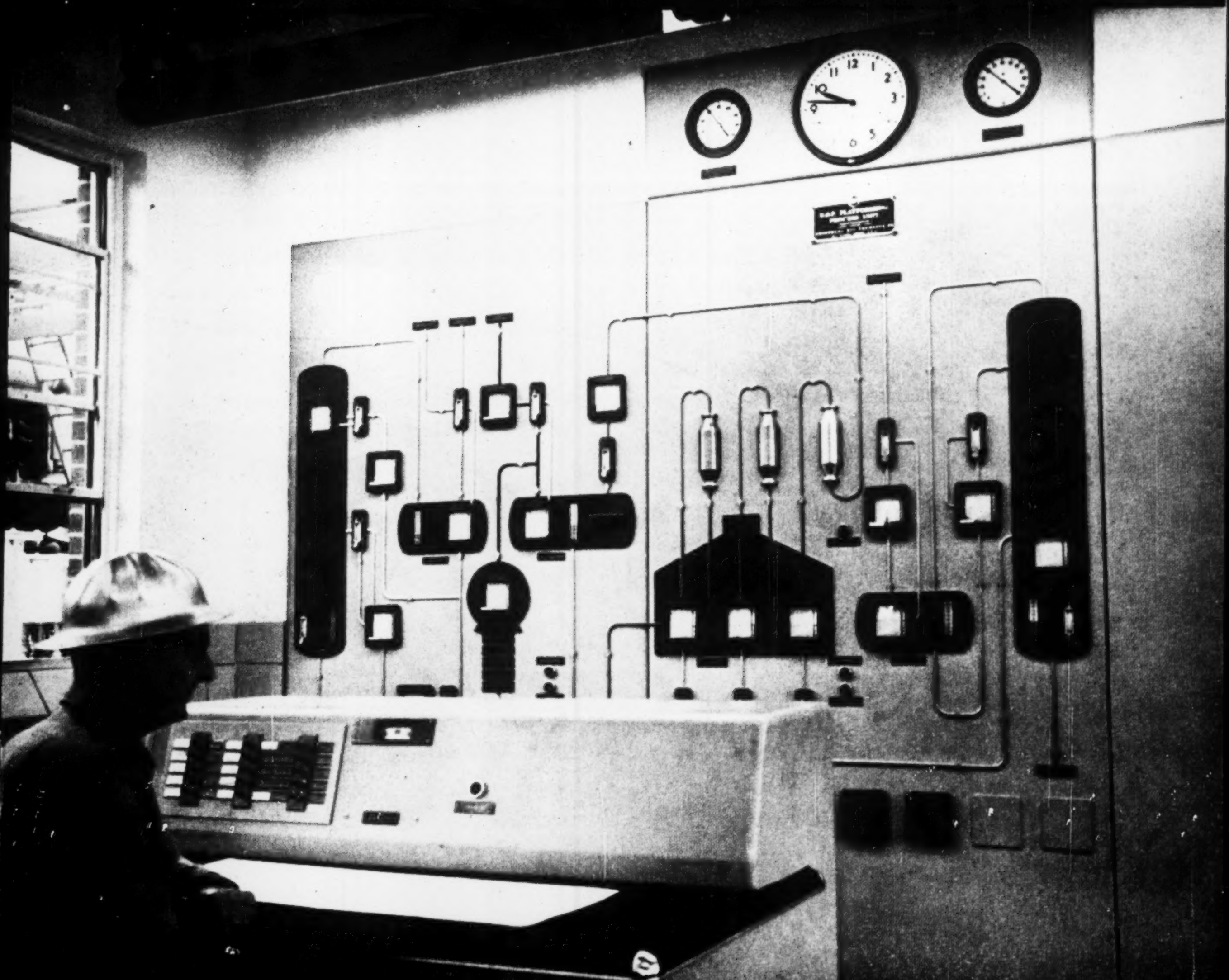
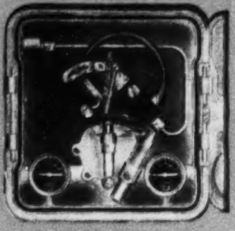
Instruments and AUTOMATION



For Precise Accuracy...Quality of Manufacture... And Outstanding Performance...

Vent Valves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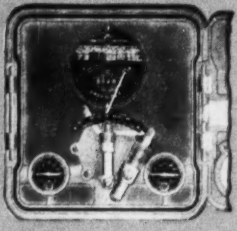
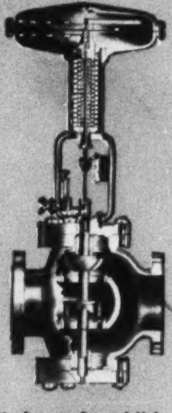

Liquid Level Control Pilots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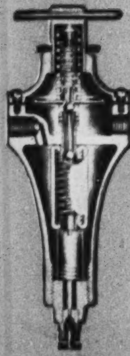
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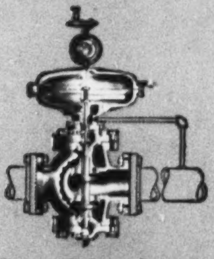
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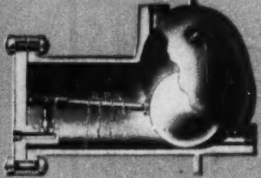
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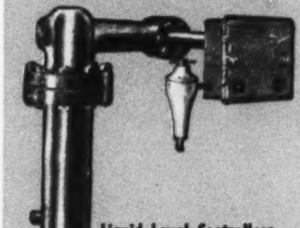
Liquid Level Controllers

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BS&B "Climax" Controls and BS&B Safety Heads are world-renowned among men in the Process Industries for their precise accuracy, superior quality and outstanding performance! Manufactured to the most exacting tolerances to comply with today's and tomorrow's newest concepts of automatic safety and process controls, they should be your *first choice* when specifying equipment for a new installation, or for replacement purposes. Call in your BS&B Representative —or write for detailed information!

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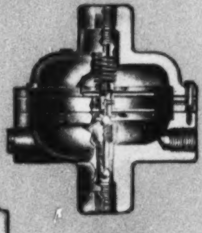
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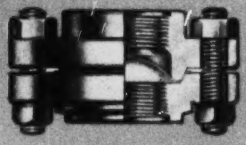
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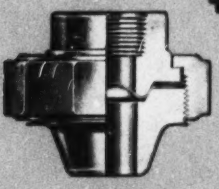
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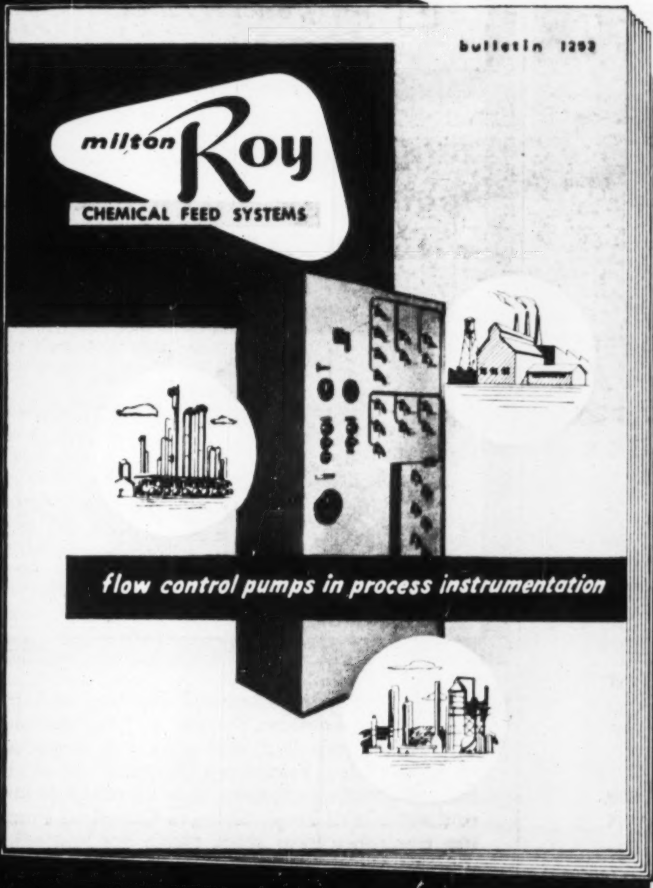
For more information circle 1 on inquiry card.

new bulletin
flow control pumps in process instrumentation



bulletin 1253

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CHEMICAL FEED SYSTEMS

flow control pumps in process instrumentation

New 24 page Bulletin describes and illustrates the application of Flow Control Pumps to chemical feed and complete instrumentation systems.

- Describes various types of controlled volume pumps—how they work, what they do.
- Contains 25 flow diagrams of typical systems including applications in the paper, petroleum, chemical, water treating and other industries.
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This Milton Roy HANDBOOK will be a valuable addition to your industrial library. Write for your copy, today!

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CONTROLLED VOLUME PUMPS AND AUTOMATIC CHEMICAL FEED SYSTEMS

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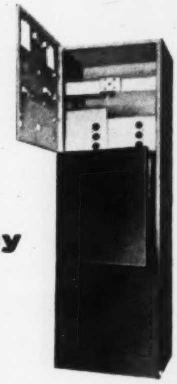
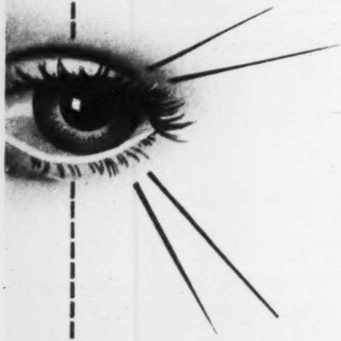
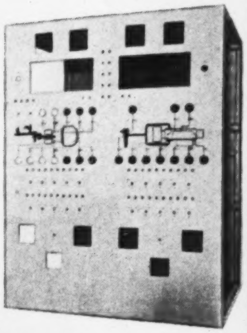
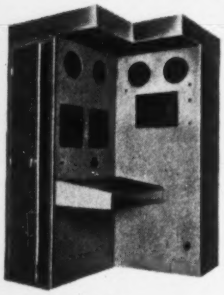
FALSTROM

"VISIONEERED" panels and control boards help improve process efficiency









Falstrom "visioneered" steel instrument and control boards, graphic panels, consoles, cubicles and cabinets are made exactly to your designs and specifications so as to achieve better functional integration of your instruments, for easier supervision with less fatigue. Falstrom fabrications are made to close tolerances and because of Falstrom's large facilities and modern equipment, no need to sacrifice or compromise on your original specifications and intentions.

Falstrom's "visioneered" construction gives you exactly what you envisage. Put Falstrom "visioneering" to work for you in accurate mountings of any size, in any metal—at low cost.

Write for Falstrom catalog of standard panels and control boards 143A or send prints and requirements for prompt estimate.

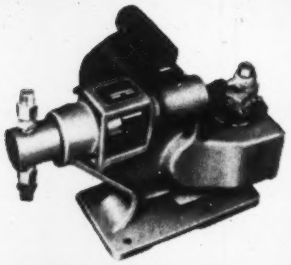
FALSTROM

FALSTROM COMPANY
92 Falstrom Court, Passaic, N. J.

For more information circle **3** on inquiry card.

- ☑ Low flows to 1 cc per hour
- ☑ High flows to 20 GPM
- ☑ Pressures as low as atmospheric
- ☑ Pressures up to 20,000 psig
- ☑ Acids to 2.0 pH
- ☑ Alkalis to 10.0 pH
- ☑ Liquids at freezing temperatures
- ☑ Hot liquids to 400° F.
- ☑ Clear liquids
- ☑ Heavy, abrasive slurries

Check your chemical feeding requirements with PROPORTIONEERS



Whatever your chemical feeding and proportioning problem, there's a Proportioneers metering pump that will give you maximum process control, maximum adjustability, at minimum operating expense. A wide range of sizes and models of Proportioneers Chemical Pumps are available from stock ready for immediate delivery.

Write for Adjust-O-Feeder Bulletin 1200, giving complete details. Proportioneers, Inc., 422 Harris Avenue, Providence 1, Rhode Island.

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PROPORTIONEERS
DIVISION OF B-I-F INDUSTRIES, INC.
METERS FEEDERS CONTROLS

Technical service representatives in principal cities of the United States, Canada, Mexico and other foreign countries.

For more information circle **4** on inquiry card.

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and **AUTOMATION**

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Editorial

First Automation Exposition 1905

Feature Articles

Digital Techniques and Binary Numbers 1944
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The Automatic Factory—A Critical Examination 1952
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Cover Story

"Autronic" installation at Rock Island Refinery. Cover illustrates central control station, showing graphic panel. For complete story see page 1948.

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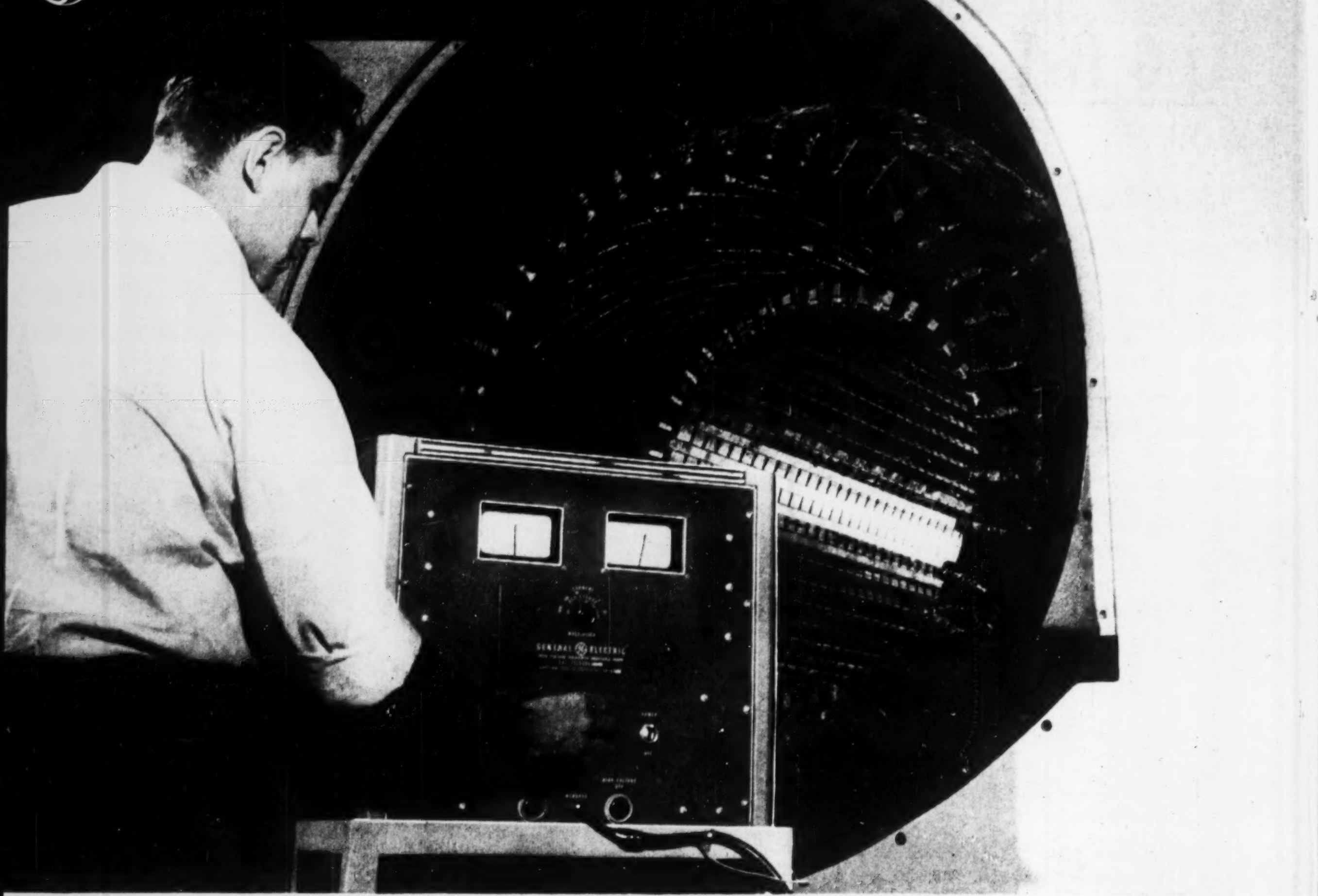
Developments in Insulation and Resistance Testing



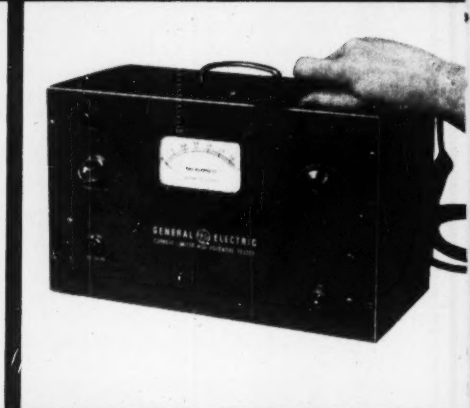
PREVENT UNTIMELY FAILURES of vital equipment like this generator stator by making non-destructive insulation tests with General Electric's new 10-kv insulation-resistance tester. Resistance measurements of installed equipment make it possible to follow insulation deterioration so that the equipment can be removed from service before the danger point is reached. Price of equipment is **$1825.20.***

More News About General Electric Instruments for Insulation and Resistance Testing

INSULATION-RESISTANCE METER

UP TO 20,000 MEGOHMS may be quickly and accurately measured on four scales of the insulation-resistance meter. With output current limited to 2 ma, greater safety for operator is assured. **$304.20.***

HIGH-POTENTIAL TESTER



CURRENT-LIMITED to a maximum of 5 milliamperes, the G-E high-potential tester minimizes most of the hazards encountered with other such equipment. No barriers, cages or white tape are needed. **$195.00.***

**Manufacturer's suggested retail price.*

For more information circle **5** on inquiry card.

GENERAL ELECTRIC ANNOUNCES . . .

NEW 10-kv Insulation-Resistance Tester; Accurately Reads up to 200,000 Megohms

Non-destructive Tests with G-E Tester Will Help To Foretell the Failure of Expensive Equipment

Now, with only one instrument, you can measure insulation resistance from 0 to 200,000 megohms at 10,000 volts d-c.

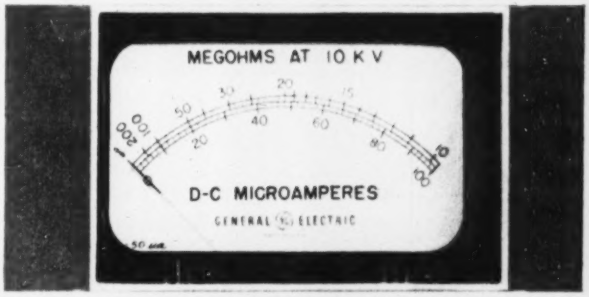
Because of this broad range, the new General Electric 10-kv insulation-resistance tester can be used to check the quality of insulation in equipment with high dielectric capacities. Such tests made before over-potential tests can help prevent the failure of expensive equipment.

MAXIMUM ACCURACY is obtained, even if the source voltage fluctuates widely, because the input of G.E.'s new insulation tester is stabilized by a synchronous motor-generator set.

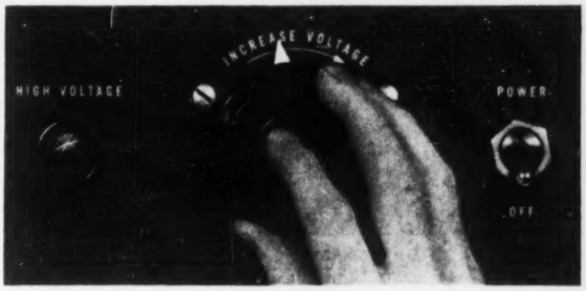
CONTINUOUSLY ADJUSTABLE OUTPUT—With the 10,000-volt d-c voltage output, which can be adjusted continuously down to zero, resistance measurements can be made near the operating voltages of the equipment. This eliminates the misleading measurements that are often made when tests are not conducted under simulated operating conditions.

VALUABLE TIME IS SAVED in making non-destructive insulation tests of equipment with large capacitances because they can be charged quickly.

For more information, contact your nearest G-E Apparatus Sales Office or mail coupon below.



FASTER TESTING is possible with G.E.'s new 10-kv insulation-resistance tester. Resistance can be read directly from the scale for the voltage specified when ordering eliminating time-consuming calculations.



OUTPUT IS CONTINUOUSLY ADJUSTABLE over the 10,000-volt range by means of this knob so that resistance measurements can be taken at or near the normal operating level of the equipment being tested.

10-KV WINDING-INSULATION TESTER

FAST, SIMULTANEOUS TESTS of turn-to-turn, coil-to-turn, and coil-to-ground insulation can be made with G.E.'s 10-kv winding-insulation tester. Dissymmetry of windings as small as one turn can be quickly detected. **$2909.40.***

SECTION B 605-83
GENERAL ELECTRIC COMPANY
SCHENECTADY 5, N. Y.

Please send me the following bulletins:

- ☐ 10-kv Insulation-Resistance Tester (GEC-1276)
- ☐ 10-kv Winding-Insulation Tester (GEC-321)
- ☐ Insulation-Resistance Meter (GEC-753)
- ☐ High-Potential Tester (GEC-700)

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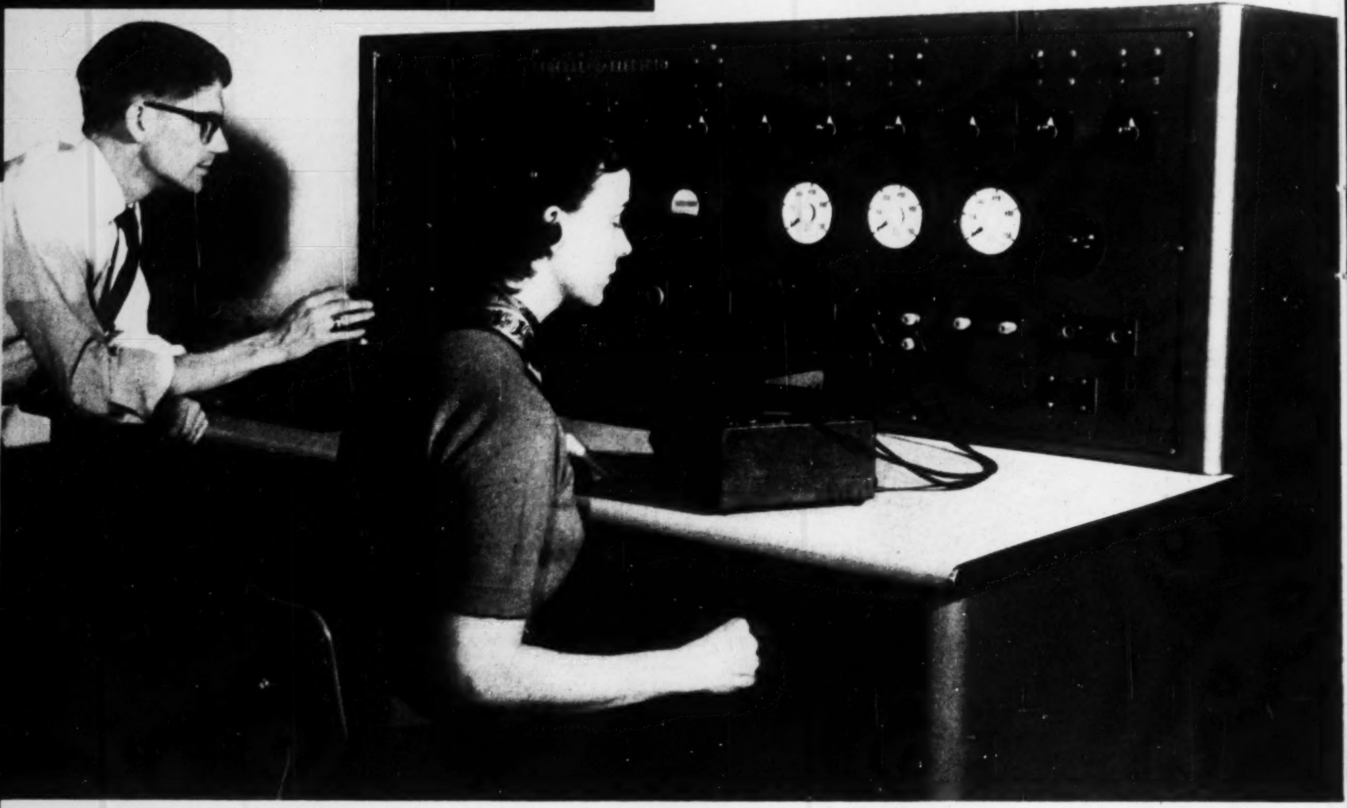
GENERAL ELECTRIC

For more information circle 5 on inquiry card.

Developments in Laboratory Instruments



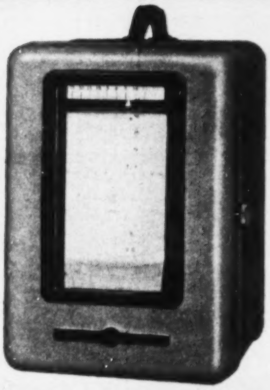
TO SAVE VALUABLE MAN-HOURS, G-E CONSOLE IS FUNCTIONALLY DESIGNED FOR SIMPLE OPERATION; FEATURES EASY-TO-REACH CONTROLS.

News About Other General Electric Instruments for Precision Measurement in the Laboratory

INSTANTANEOUS VAPOR DETECTOR

FOR HEALTH MONITORING of mercury vapor and certain other toxic vapors, this portable General Electric instrument pinpoints contaminated areas; can be used wherever 115-v., 60-cycle power is available. $495.00.*

PHOTOELECTRIC RECORDER



RECORDING RAPIDLY CHANGING PHENOMENA with minimum load on measured circuit, recorder is available with sensitivity as low as 1 ua full scale. Response times as low as 1/5 second. $700.00.*

**Manufacturer's suggested retail price.*

For more information circle **6** on inquiry card.

Minimize Calibration Time With Versatile, Easy-to-use General Electric Instrument Standardization Console

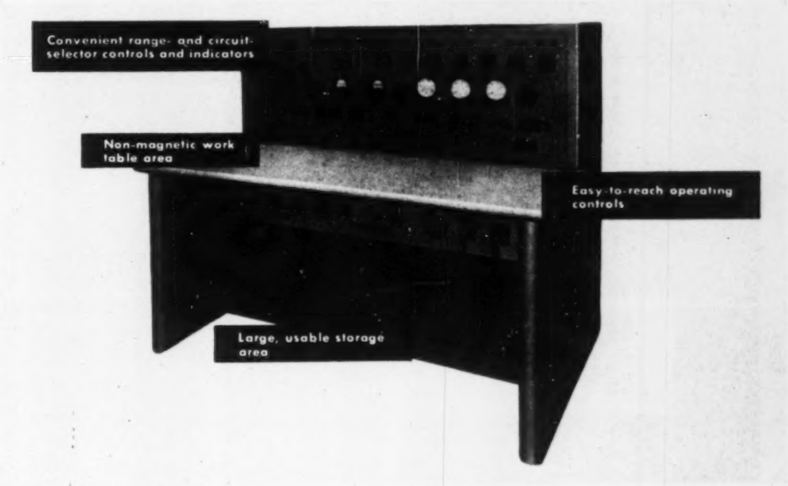
PROVIDES REGULATED POWER SUPPLIES FOR PRECISE INSTRUMENT CALIBRATION

The General Electric instrument standardization console provides regulated power supplies for precise calibration of a wide range of electric instruments.

HIGHLY ACCURATE, the console provides facilities for referring both d-c and a-c measurements to a standard cell, or to a laboratory standard instrument.

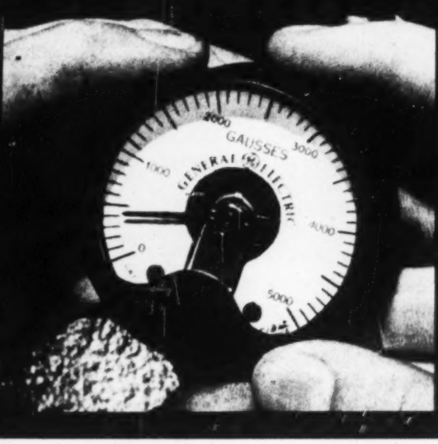
WIDE RANGES of a-c and d-c power supplied by the console facilitate the calibration of voltmeters, ammeters, frequency meters, and many others. Both a-c and d-c standardization tests can be made up to 750 volts, or 150 amperes; with low-distorted a-c frequencies from 50 to 3000 cycles.

FOR FURTHER INFORMATION about the General Electric instrument standardization console, contact your nearest G-E representative, or clip coupon below for Bulletin GEA-6005.


Convenient range- and circuit-selector controls and indicators
Non-magnetic work table area
Easy-to-reach operating controls
Large, usable storage area

HIGHLY VERSATILE, the General Electric console has necessary switches, busses and indicators for calibration of a-c and d-c laboratory-standard, portable, small-panel, switchboard, and recording instruments. Requires only normal 115-v, 60-cycle source.

GAUSSMETER



CONVENIENT, POCKET-SIZE G-E meter facilitates checks of flux density and direction in magnetic gaps. Ideal for use in small or congested areas. Price including reference magnet and case, $67.10.*

INDICATING FLUXMETER

HIGH ACCURACY AND SENSITIVITY combine to provide precise magnetic measurement. Accuracy is ±1% of full-scale deflection; sensitivity is as high as 1 millimeter deflection per 100 flux lines. Price is $278.50.*

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Please send me the following bulletins:

- ☐ **Instrument Standardization Console (GEA-6005)**
- ☐ **Instantaneous Vapor Detector (GEC-1275)**
- ☐ **Photoelectric Recorder (GEC-245)**
- ☐ **Equipment for Measuring Magnetic Properties (GEC-777)**

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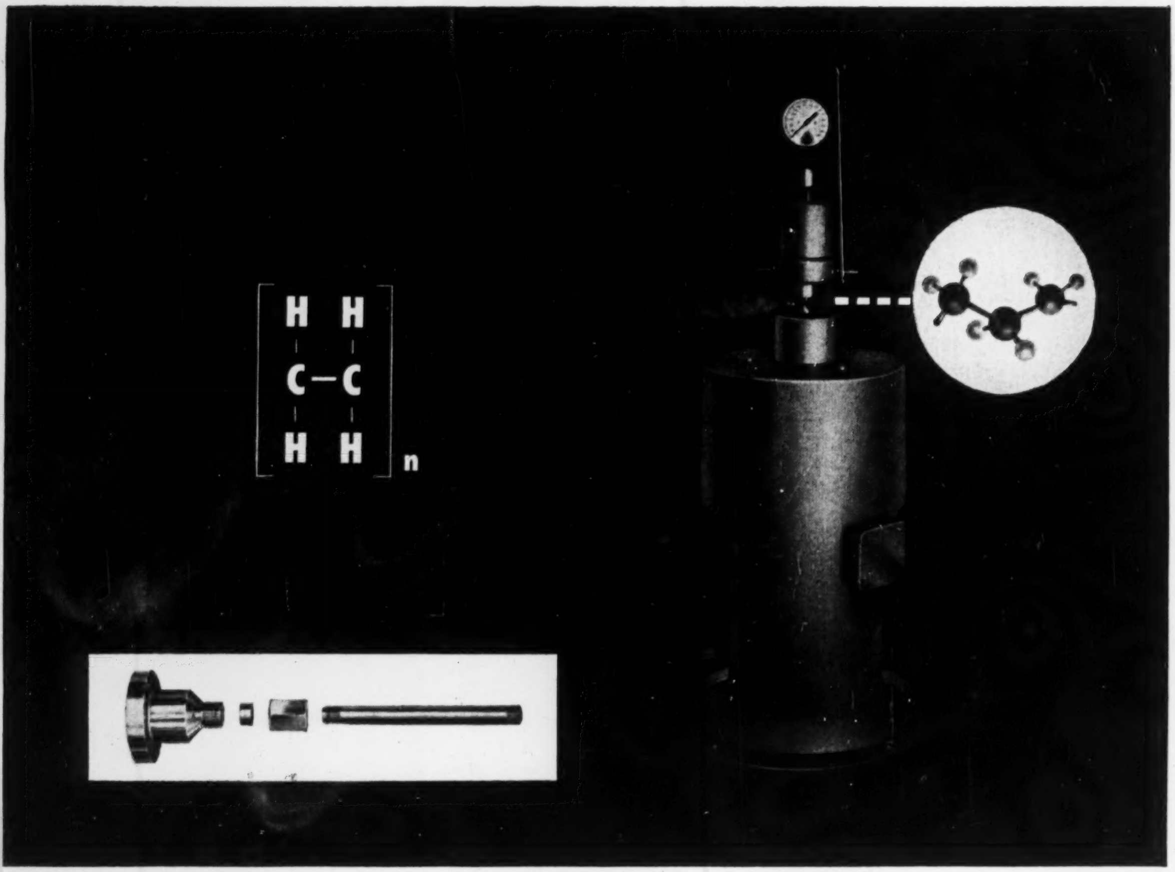

TUBING BY SUPERIOR SAVES 33% on production cost of Autoclave covers!

Shown here is the Magne Dash* autoclave, a "dash pot" used to test physical and chemical properties of materials under high pressures.

The Magne Dash cover now costs far less to make than it used to. For in redesigning it, Autoclave Engineers, Inc., Erie, Pa. found that Superior cold drawn Type 316 stainless steel tubular component gave them amazing economies. Savings 33%.

Originally, 2" stainless steel forgings were used in the Magne Dash cover. These had to be machined and deep drilled—time-and-money consuming operations. Superior tubing eliminated this expensive work and reduced scrap loss almost to zero! At the same time, minimum yield strength was raised from about 40,000 psi to 100,000 psi. And Autoclave Engineers found Superior tubing easy to thread, easy to clean and unusually resistant to corrosive catalysts used in testing.

If you have a problem in high pressure processing—or any other problem that involves tubing—call on Superior. We make a specialty of fine tubing—in special shapes and sizes—and in more than 55 analyses! Out of our long experience, you are sure to get the answers you want. Tell us about your current production problem. Send for our free Catalog Section 20 on stainless steel tubing. Superior Tube Company, 1968 Germantown Ave., Norristown, Pennsylvania.

*Licensed by Standard Oil Company (Indiana) U.S. Patents 2631091 and 2661938

Round and shaped tubing available in Carbon, Alloy and Stainless Steels; Nickel and Nickel Alloys; Beryllium Copper; Titanium; Zirconium

Superior Tube

The big name in small tubing

All analyses .010" to ⅝" O.D.
Certain analyses in light walls up to 2½" O.D.

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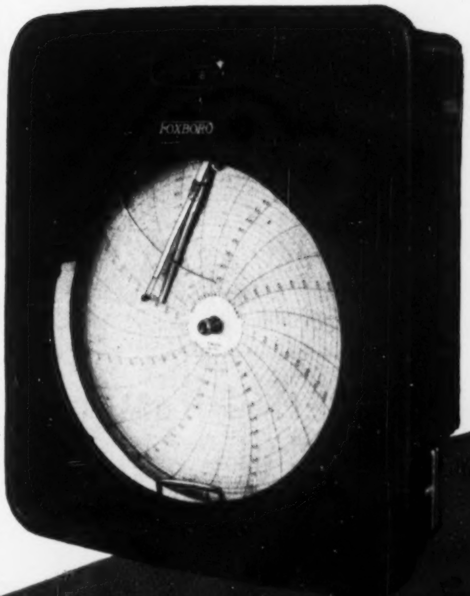
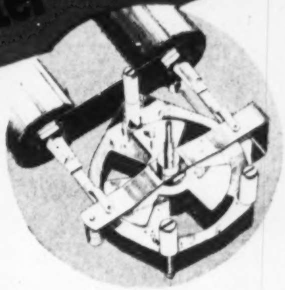
An unbeatable pyrometer for any range between -300° and +2800°F.



DYNALOG* . . . the electronic potentiometer that has no slidewire!



This simple variable capacitor is important to potentiometer users because it eliminates the conventional, troublesome slidewire altogether; and it gives Dynalog Instruments the continuous *stepless* balancing which assures higher accuracy, closer control.

Reg. U.S. Pat. Off.

. . . no batteries to standardize!

TOPS in simplicity . . . unequalled in its combination of accuracy, sensitivity, and speed of response . . . the Dynalog Potentiometer with standard thermocouples gives you unerring temperature measurement for any range up to 2800°F. Featuring *sustained* accuracy of ¼ of 1% of scale, it's an instrument of laboratory precision built to withstand the severest industrial conditions.

Unprecedented freedom from maintenance is the direct result of unique Dynalog design. There's no slidewire, no battery to standardize. There are no gears, belts, or high speed reversing motors. There's nothing to wear and cause dead space.

Single pen recording models provide full scale pen travel in 3 seconds standard, or as fast as 1 second without extra cost. The Multi-Record Dynalog provides color-coded records of up to 6 points at 6 second intervals. Both types give the convenience and low cost of circular charts.

Dynalog Potentiometers are also used for the measurement of pH, oxidation-reduction potential, and for other applications in which the process variable can be converted to a dc millivolt signal. They are available for pneumatic or electric control.

Write for your copy of Bulletin 427-1 which gives the whole story.

THE FOXBORO COMPANY, 4612 NEPONSET AVE., FOXBORO, MASS., U.S.A.

FOXBORO POTENTIOMETERS

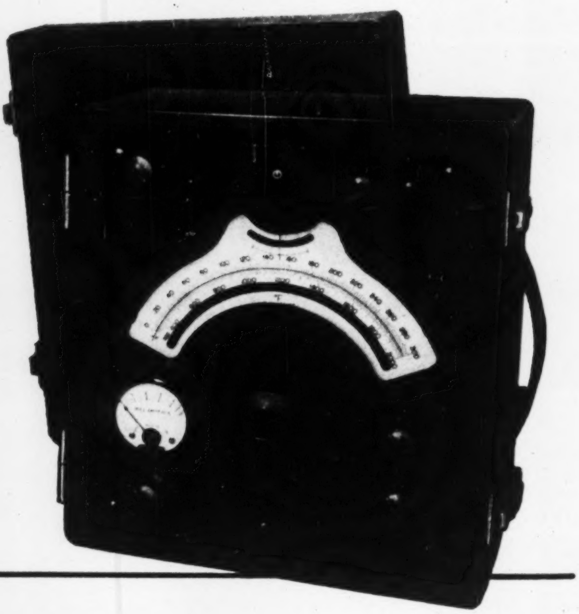
FACTORIES IN THE UNITED STATES, CANADA, AND ENGLAND

For more information circle 8 on inquiry card.

LEWIS PORTABLE PYROMETER POTENTIOMETERS

FOR MEASURING TEMPERATURES ELECTRICALLY

- IN MOVING VEHICLES
- IN AIRCRAFT
- IN THE LABORATORY



ACCURATE, DIRECT-READING, EASILY-OPERATED INSTRUMENTS, WITH ELECTRICAL COLD-JUNCTION COMPENSATION.

These potentiometers have been used for years by the leading motor car and aircraft manufacturers for proving-ground and flight-test work as well as in the laboratory.

- Three models from which to choose the instrument for your application.
  - Model 13PO2, with single temperature scale.
  - Model 14PO (illustrated) with high and low temperature scales.
  - Model 78PO with one temperature and one millivolt scale or two temperature scales, for different thermocouple materials.
- Housed in a sturdy hardwood case, approximately 11⅜" long, 10" wide and 7⅞" high. Weight approximately 17 lbs., shipping weight 20 lbs.
- For dependable temperature instrumentation, use these potentiometers with LEWIS leads, selector switches and thermocouples.

THE LEWIS ENGINEERING CO.
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Manufacturers of Complete Temperature Measuring Systems for Aircraft

For more information circle 9 on inquiry card.

Trends...

Instruments and AUTOMATION

Radioisotope market is expanding. In 1954 there were more than 1000 industrial users, 800 medical, and 500 other users. Potential is high.

"Industrial segment of electronics industry . . . . may have greatest rate of growth of all," said J. Halligan, President and Board Chairman of Hallicrafters Co., referring to industrial controllers, computers, automation of manufacturing processes, etc. Government purchases of electronic equipment during second quarter of 1954 are much lower than for corresponding period in 1953; but industrial purchases are up.

Growth of instrument industry is pointed out by Bureau of Labor Statistics: number of employees in instrument and scientific apparatus manufacturing was 39000 in 1951, 49000 in 1952, 54000 in 1953. Largest growth was in industrial-instrument field, with 8.6% increase in shipments of industrial instruments in 1953 over 1952.

Analog computer purchases (gross) are expected to be $8-10 million for 1954; $15-$20 million for 1955. Over $40 million worth of analog computers are in current use; industrial market is expected to "break" soon with great increases at operational level.

Electronic firms in Los Angeles area reported billings of $750 million in 1953; billings in 1946 were less than $100 million.

"Real future of magnetic recording lies in area of instrumentation and in the field of computers, business machines, and control mechanisms," says S. J. Begun, vice-president Clevite-Brush, at recent AIEE meeting, although audio market ($200 million in 1953) is still growing.

World-wide demand for Geiger counters followed disclosures of radioactive tuna fish in Japanese home waters. Japanese atomic instrument industry could not meet demand.

New trend in oscilloscopes: large (21-inch) screens have been announced by Technomatic and Electromec. New trend in cable checkers: automatic high-speed multiconductor cable inspectors have been announced by Panascan and Link Aviation.

New physical principles are used rapidly in instrumentation. Nuclear magnetic resonance spectroscopy was discovered only a few years ago; instruments are now available for nondestructive rapid analysis of liquid samples (including melted solids and liquified gases) by n-m-r analysis, an outgrowth of nuclear physics research.

New field attracting attention is radio remote control of fork lift trucks, bridge cranes, materials-handling tractor-trains, railroad switching car yards, etc. "Sensational" developments are on the way for automatic handling of hot and cold forged parts.

Aircraft industry calls for lighter components. Each pound added to an aircraft requires 10 additional pounds in powerplant and supporting structure if performance is held constant.

Atomic Power Equipment Component has been formed by the General Electric Co. Schenectady, to market atomic power equipment for commercial use.

Research expenditures for current fiscal year are about $4 billion, with $2 billion spent by industry and private organizations, and $2 billion by federal government. About 85% of government spending ($1.7 billion) is related directly to defense and security.

Do these
5 NEW ASCO SOLENOID VALVES
meet a special need for you?

Five completely new solenoid valves were developed by ASCO during 1954. Smaller size, greater efficiency and longer reliable life fit these valves to specific industrial uses.

ASCO
8210A2

A NEW ASCO 2-WAY SOLENOID VALVE

COMPACT: Only 2¾" face to face; 3¹³⁄₁₆" overall height.

Simple: Just two operating parts. Can be mounted in any position. Low power consumption. Standard, explosion proof or watertight solenoid enclosures. Normally open or normally closed.

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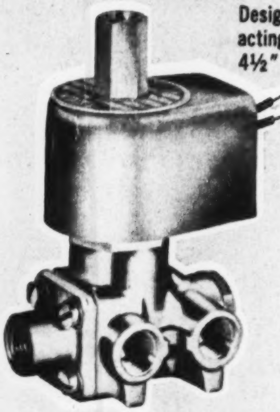
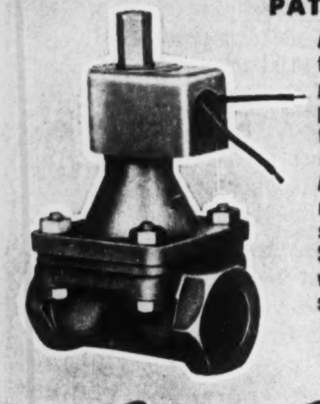


A NEW ASCO 4-WAY MIDGET SOLENOID VALVE

Designed for control of small double acting cylinders. Compact: Under 4½" high, 2" wide, 2" deep with standard NEMA I solenoid enclosure. Operates up to 400 cycles per minute mounted in any position. Standard, explosion proof or watertight solenoid enclosures.

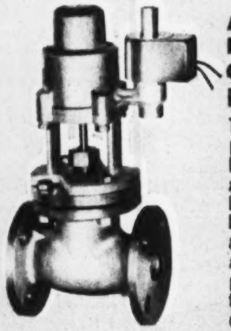
BULLETIN 8345



A NEW ASCO SOLENOID PILOT CONTROL VALVE WITH SAUNDERS PATENT TYPE BODY

Absolutely tight shut-off control for corrosive liquids and gases. The dependable ASCO pilot provides automatic control of main diaphragm valve using auxiliary pressure. Available normally open or normally closed in a wide selection of body materials. Standard, explosion proof or watertight solenoid enclosures.

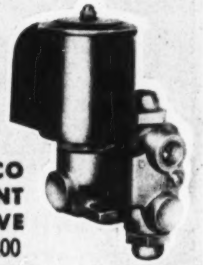
SPECIAL BULLETIN 8336



A NEW ASCO CORROSION RESISTANT, CYLINDER OPERATED 2-WAY VALVE

BULLETIN 8338

Two valves designed specifically for processing plants where corroding liquids or gases are handled. Many types of body materials available. Standard, explosion proof or watertight solenoid enclosures.



A NEW ASCO CORROSION RESISTANT 3-WAY SOLENOID VALVE

SPECIAL BULLETIN 8300

Write for additional details on any of these valves. Please specify bulletin number.

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ASCO *Solenoid* VALVES

Automatic Switch Co.

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For more information circle 10 on inquiry card.

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directly from
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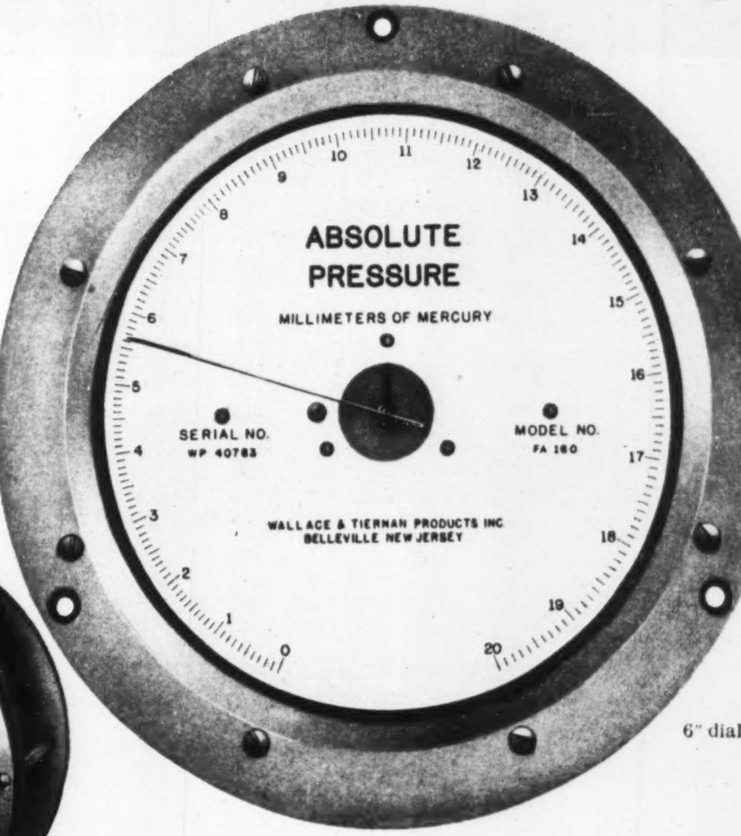
ABSOLUTE PRESSURE
MILLIMETERS OF MERCURY
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
SERIAL NO.
WP 40783
MODEL NO.
FA 160
WALLACE & TIERNAN PRODUCTS INC
BELLEVILLE NEW JERSEY

6″ dial

ABSOLUTE PRESSURE
0
2
4
6
8
10
12
14
16
18
20
MM MERCURY

2¾″ dial

Used as a pressure indicator in any system employing a vacuum.

- All readings are relative to ZERO ABSOLUTE.
- Dial *reads directly*.
- Accurate to 1 part in 300 over full scale.
- Sensitive to 1 part in 500 in *all* ranges.
- No auxiliary indicator or corrections for ambient pressure changes required.
- Protected against sudden pressure surges.

— Ranges:	0.1– 20mm Hg.	0–200mm Hg.
	0 – 50mm Hg.	0–410mm Hg.
	0 –100mm Hg.	390–800mm Hg.
— Dial Sizes:	All ranges in either 2¾″ or 6″ dia.	

TYPE FA-160

For additional information on W&T Absolute Pressure Indicators, write today for Publication No. TP-28-A.

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For more information circle **11** on inquiry card.

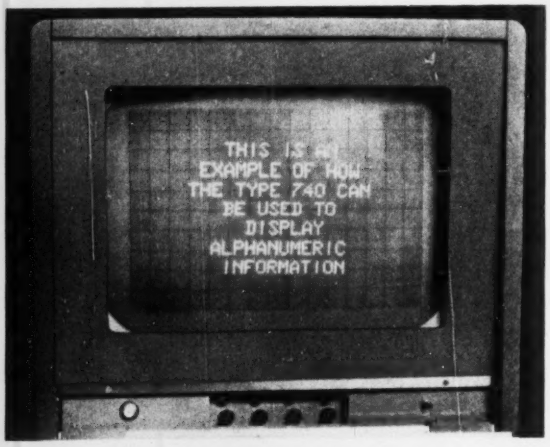
INSTRUMENTS ON THE MARCH

New Principles, Applications, Non-commercial Developments

Computer CR-tube Display

NEW YORK, N. Y.—"Giant brains" soon will be provided with "windows" which show what goes on inside the electronic craniums. These are cathode-ray tubes on which the calculators' function and outputs will be pictured in the form of graphs, geometrical figures, engineering symbols, or in words and numbers (alphanumeric display).

The new device, announced by International Business Machines Corporation, is known as the "Type 740 Cathode Ray Tube Output Recorder," and was designed for use with IBM's "Type 701 and 704" Electronic Data Processing Machines, eighteen of which are now in use by leading American industries and in government agencies.



THIS IS AN
EXAMPLE OF HOW
THE TYPE 740 CAN
BE USED TO
DISPLAY
ALPHANUMERIC
INFORMATION

Transistor Production

PHILA., PA.—Engineer peers at a germanium seed as it is "pulled" during growing process in Minneapolis-Honeywell's plant. Critical temperatures and programming functions are regulated by the electronic recorder (left). The crystal is later used in one of the power-type transistors now being mass-produced by the firm. Recently, M-H unveiled a new super-power transistor capable of delivering up to five amps of electric current to a motor. The new model transistor is designed for a wide variety of applications including operation of motors, output sections of high-power audio systems, etc.

UNIVAC and the Elections

NEW YORK, N. Y.—Many exaggerated reports have been made to the effect that the "giant brain" UNIVAC did or did not "predict" the recent national elections. Hence it is interesting to examine how UNIVAC performed.

The "problem" of forecasting results is purely mathematical, based on "samples" taken from previous elections, back as far as 1944. This is the same basis of calculations upon which pollsters draw their conclusions except that UNIVAC is much faster, and does not make errors. These samples include previous results from various political areas throughout the country which are compared electronically with results as they come in.

As a matter of fact, UNIVAC's first prediction of "most likely results," based entirely on previous election results and released shortly after the first polls closed, showed the Democrats winning 227 seats in the House, and the Republicans 207—which was only five votes away from the final result.

When UNIVAC made its first prediction, based on previous voting, before the first returns came in over the CBS teletype, UNIVAC made a series of calculations and came up with answers which—translated by the experts—said in effect:

"On the basis of previous election returns the chances are three to one the Democrats will get between 225 and 230 seats in the House. The same odds give the Republicans between 204 and 209 seats."

Each of these figures was split—the difference between 225 and 230, for example, being 227; thus the first pre-

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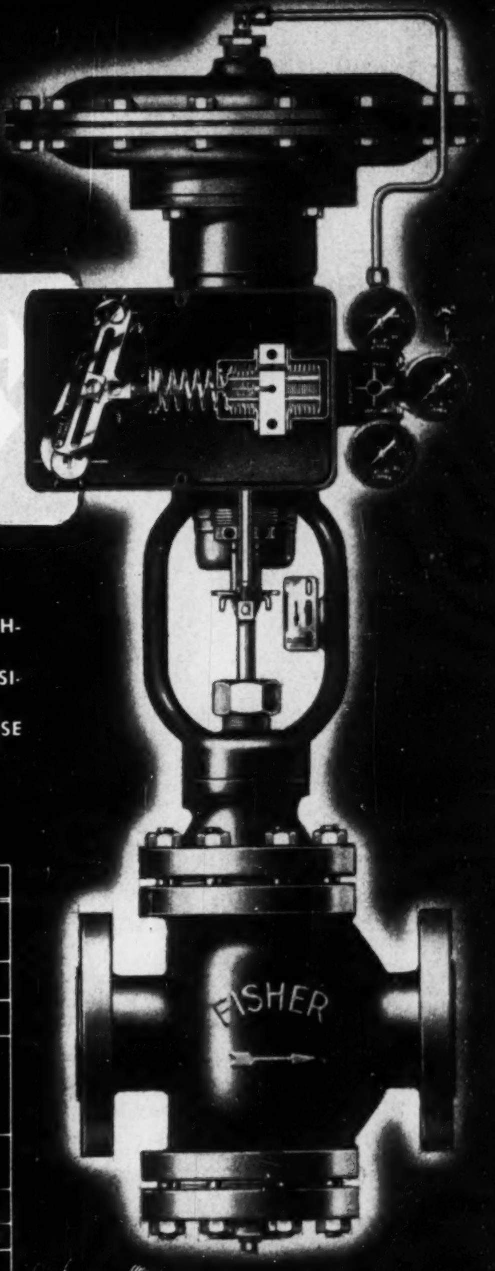

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TECHNICAL DATA

TEST			FISHER TYPE 3500
INSTRUMENT PRESSURE SENSITIVITY CONTROLLING PRESSURE CHANGE NEEDED TO PRODUCE 2 LBS. TO 15 LBS. TO DIAPHRAGM			0.07 LB
STEM MOVEMENT SENSITIVITY AMOUNT STEM CHANGE TO PRODUCE 2 LBS. TO 15 LBS TO DIAPHRAGM	½" TRAVEL		0.0037" AVE.
	2" TRAVEL		0.015" AVE.
SPEED TIME IN SECONDS FOR FULL TRAVEL	SIZE	TRAVEL	
	DD	¼"	1.2 — 1.2 SEC
	FF	1½"	4.2 TO 4.8 SEC.
	GG	2"	7.2 SPC TO 9.6 SEC.
	HH	2"	10.5 TO 12.6 SEC.
LAG ERROR IN POSITION AT 9 LBS. CONTROLLER PRESSURE	½" TRAVEL		0.0006" AVE.
	2" TRAVEL		0.001" AVE.
EFFECT OF VARIATIONS IN AIR SUPPLY PRESSURE	½" TRAVEL		0.1 LB. PER 5 LB. CHANGE
	2" TRAVEL		0.1 LB. PER 5 LB. CHANGE
CHARACTERISTICS CONTROLLED P VS DIAPHRAGM P			LINEAR
COMMENTS			STABLE ADJUSTMENTS ALL EASY AND SIMPLE
AIR CONSUMPTION NORMAL 9 LBS. DIAPHRAGM PRESSURE			15.0 CU FT/HR

FOR COMPLETE DETAILS WRITE FOR BULLETIN E-3500.

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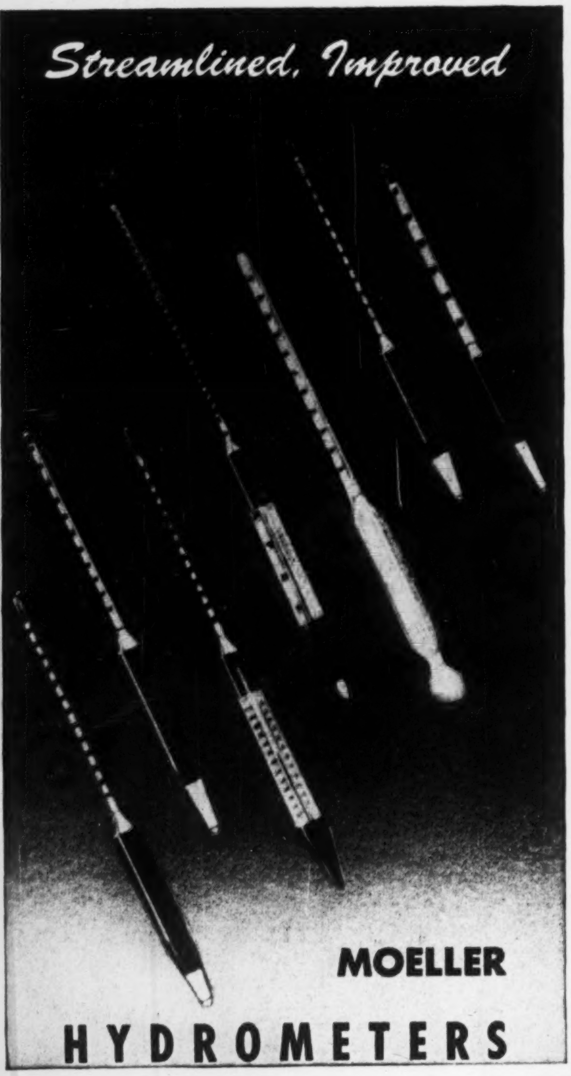

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For more information circle 13 on inquiry card.

ON THE MARCH—CONTINUED

diction was 227 to 207—which was almost on the nose.

However, as returns came in over the CBS teletype, the current voting began to weight these forecasts. Certain areas voted more heavily Democratic than they had previously; and other areas, regarded as predominantly Republican, such as upstate New York where snowstorms impeded getting in the returns, failed to show strongly in the comparison with the "samples."

Therefore the forecast shifted more heavily in favor of the Democrats, and CBS announcers said UNIVAC had "predicted a Democratic landslide."

Actually, what UNIVAC said in effect was:

"On the basis of returns thus far, the most likely result will be: In the House, Democrats 299 seats, Republicans 135 seats; and in the Senate, Democrats 56 seats, Republicans 39 seats."

When more returns rolled in, the unusual factors began to balance out, and the forecast of "most likely results" narrowed down.

The big computer proved that it could act like a human prophet—"hedging" on its bet as election returns piled up. Once it offered "three-to-one odds" that the Republicans could win the Senate by one vote, if all close races were won by Republican candidates.

At 10:30 P.M. on election night, UNIVAC reported the "most likely result" would be 227 Democrats and 207 Republicans in the House—exactly as it reported on its first forecast. At this point "human error" jumped into the situation with a vengeance. The teletype reported the prediction to CBS in reverse, giving the Democratic figures as Republican and vice versa, and CBS announced that UNIVAC had switched.

A few frantic telephone calls rectified this mistake, and UNIVAC continued throughout the night to predict a Democratic sweep of both houses, which was confirmed in final tabulations.

It was 24 hours after the polls closed that the final results confirmed UNIVAC's first prediction—that the Democrats would win both houses.

This is UNIVAC's second experience as a political prognosticator. In the 1952 presidential race, Remington Rand's "giant brain" predicted at 8:30 P.M., an hour and a half after eastern polls closed, that General Eisenhower would carry 43 states, with 438 electoral votes, against Governor Adlai Stevenson's five states with 93 electoral votes. In the final returns, General Eisenhower carried 39 states with 442 electoral votes and Governor Stevenson took nine states with 89 electoral votes.

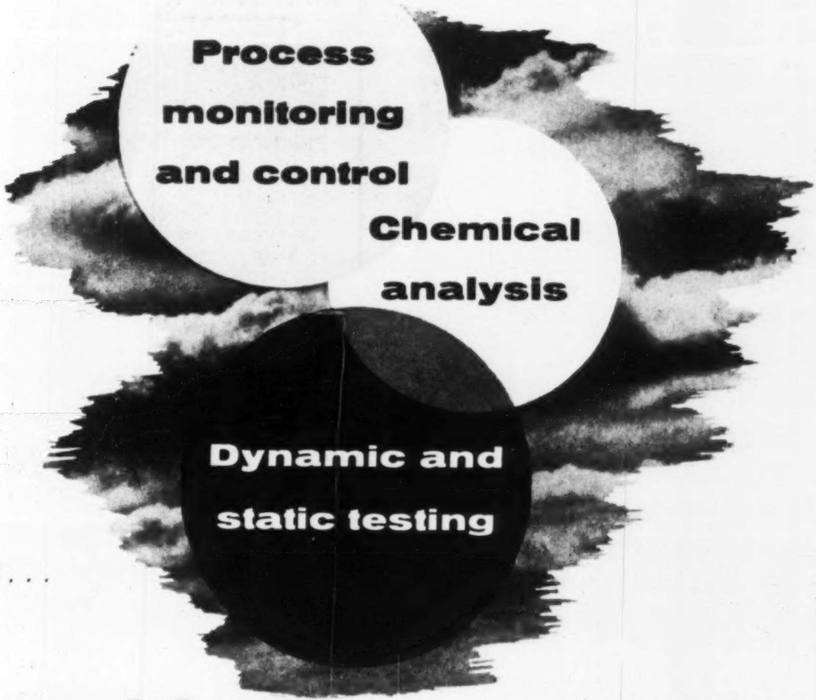
The forecast by UNIVAC at that time was so startling that the human brains operating the "giant brain" refused to accept the forecast, doping the computer with various "weighting" devices such as newspaper polls, until UNIVAC came out almost even, at one point, giving Governor Stevenson the edge in popular votes and General Eisenhower the election.

Hurricane Tests Recorder

HAMPTON, VA.—When hurricane Hazel crashed across Virginia on her recent non-stop trip north, a new-type Wind Velocity Recorder, advertised as being "rugged as it is accurate," got a test to end all tests.

First, the windy lady turned the public eye on the instrument by knocking out all contact between the regional Weather Bureau and the hard-hit Virginia cities of Hampton, Newport News, and Warwick—leaving the highly lauded device as the sole source of information for the area.

Atop the Hastings Instrument Co., Hampton manu-



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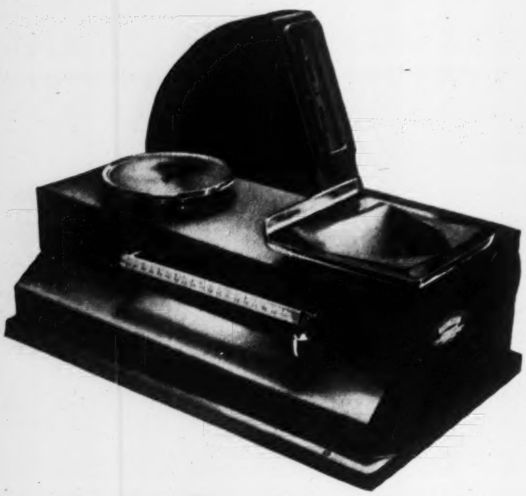

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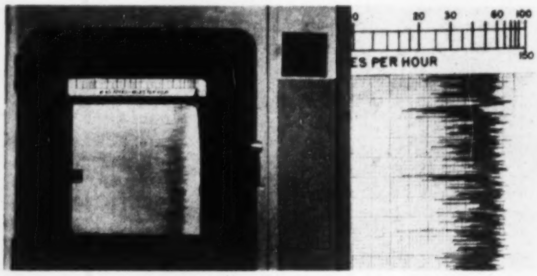
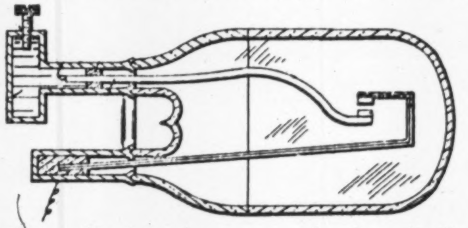


facturers of the indicator, the probe (sensing element) of the recorder stood its ground while Hazel slapped it with buffeting gusts which repeatedly approached 100 mph. and once reached 130. Then Hazel picked up the 10′ x 8′ weather platform and slammed it to the roof. That did it. Although Hazel herself had not damaged the device the fall ended one of the stiffest instrument tests on record.

Bourdon-operated Vacuum Switch

PHILA., PA.—Patent No. 2,356,174 reveals a device of potential usefulness in automatic control. It is a vacuum-enclosed electric switch operated by a Bourdon-tube element also enclosed in the vacuum chamber. Application possibilities exist wherever an explosion-proof high-power switch is needed that can be operated by small movements, temperature-induced fluid expansions, pressure changes, etc. The patent is available for licensing or purchase from Mr. H. Olken, 1042 Beech Ave., Glenolden, Pa.

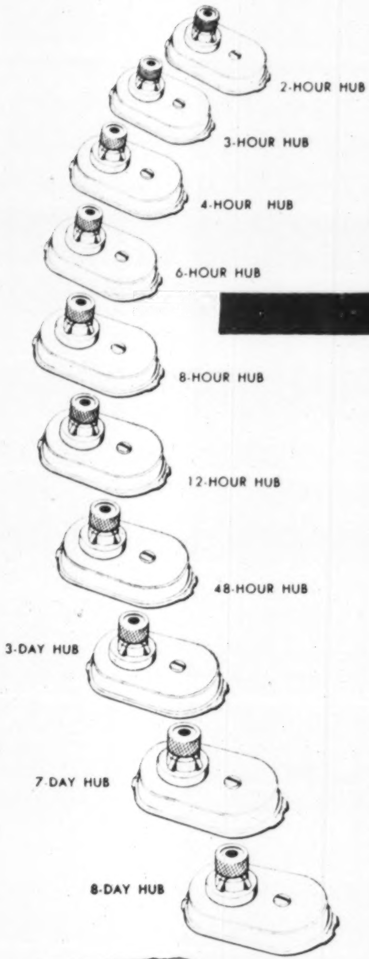


Analytical Instrument Clinic

PHILADELPHIA, PA.—The penetration of instrumentation into the chemical laboratory and industrial plant was demonstrated by the registration of 500 engineers and scientists at the Third Analytical Instrument Clinic; instruments worth over $100,000.00 were used for the course.

The companies that furnished instructors and instruments were the Applied Research Laboratories, Bausch & Lomb, Beckman Instruments, Inc., Consolidated Engineering Corporation, General Electric, Liston-Becker, and Varian Associates. The instruments covered were: X-Ray Quantometer, Littrow-Echelle Spectrograph, Infrared Spectrometer, Process Monitoring Mass Spectrometer, Ion Resonance Mass Spectrometer, Non-Dispersion Infrared Analyzer, and Nuclear Magnetic Resonance Spectrometer. Every instrument functioned properly for the whole period.

The Analytical Instrument Clinic Committee is a subcommittee of the Analysis Instrumentation Committee, ISA. The chairman of the latter is Mr. T. C. Wherry. The Clinic committee is composed of Dr. E. J. Rosenbaum, Dr. Ralph Munch, Mr Ellis Rump, and Dr. Axel H. Peterson, Chairman.



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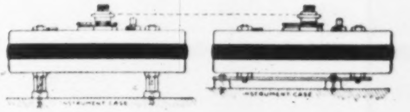
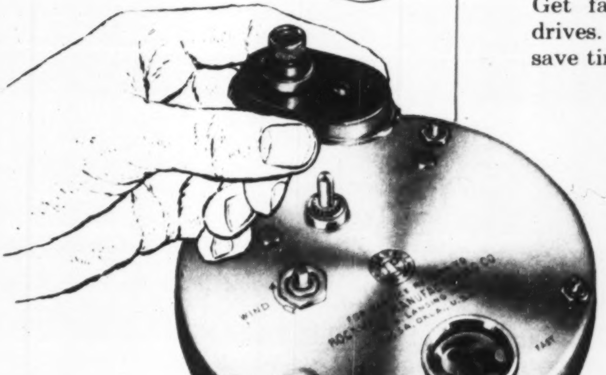
FOR REPLACEMENT SERVICE, the Rockwell chart drive is the most versatile, economical you can use. Design dimensions were deliberately established so that the drive can be adapted to fit practically all instruments. One adaptor is furnished with each drive. There is no problem with rotation rates either. Speed changing turrets lock onto the chart arbor of the Rockwell drive to provide any one of 11 rotation cycles. Think what these features mean to you in reduced chart drive inventory, servicing and all-around flexibility of application.

Get facts now on versatile, long-lived Rockwell chart drives. Learn how their use in your instrument shop will save time and money. Write for bulletin 1079.

ADAPTORS TO FIT PRACTICALLY ANY INSTRUMENT



Illustrations show how adaptors are used to correctly locate Rockwell chart drives within instrument cases both as to position and height.



The Turret On Top Does The Trick

Illustrating how the speed changing turrets are applied to the chart arbor to provide a wide selection of rotation rates.

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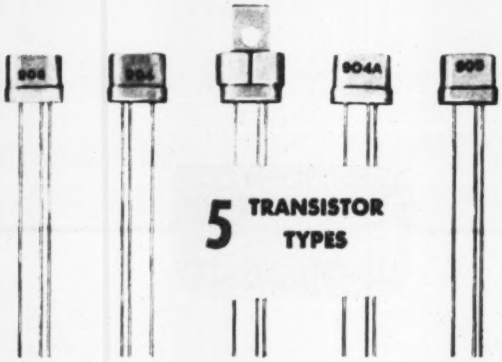
HIGH VOLUME PRODUCTION of *silicon* semiconductor devices enables Texas Instruments to offer you an enlarged line of five types of silicon transistors and two types of silicon junction diodes . . . all available for immediate delivery in production quantities!



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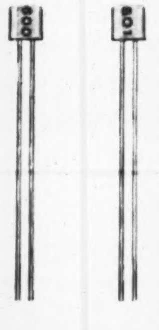

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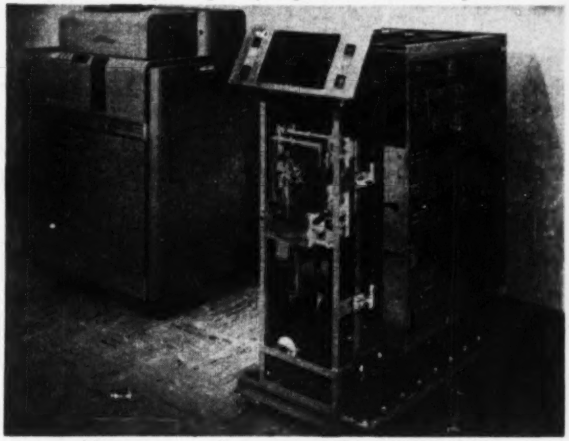
ON THE MARCH—CONTINUED

Transistorized Computer

POUGHKEEPSIE, N. Y.—An experimental "all-transistor" calculator with a computing unit about one-half the size and requiring only 5-percent as much power as a comparable vacuum tube unit was demonstrated at a press preview of IBM's new Poughkeepsie, N. Y., research laboratory.

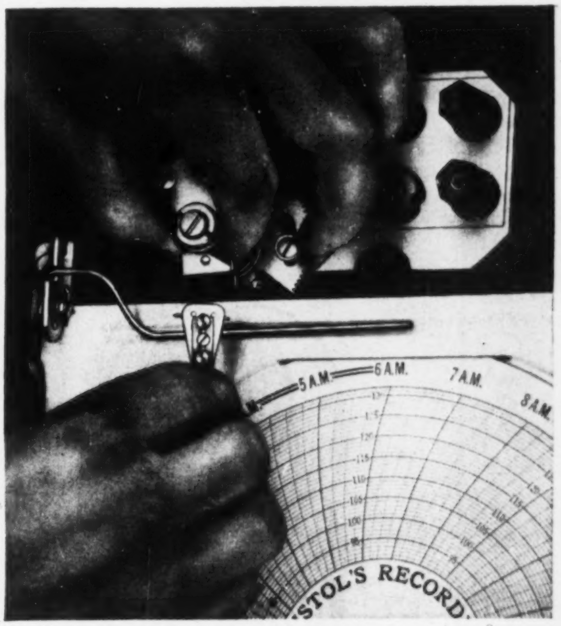


The new machine is comparable in capacity to IBM's "Type 604" electronic calculator, of which over 2,000 are in use, it was said. (The 604 uses 1,250 vacuum tubes.) While their speeds are similar, the two machines provided a sharp contrast in size. This experimental engineering model is believed to be the first fully-operative transistorized computer complete with automatic input and output. More than 2,200 transistors are used in the machine.

SIMAC

NEW YORK, N.Y.—"SIMAC," the first instrument simultaneously applying ultrasonics and digital automation to parts inspection as production-line procedure, has been developed by Sperry Products, Inc., of Danbury, Conn., at a cost of $300,000. "SIMAC" means sonic inspection, measurement, and control. It is being installed in the Quality Control Department of Allison Division, General Motors Corp., specifically for the inspection of jet engine rotor forgings and other unfinished engine parts.

Completely scanning a circular part mounted on a rotating turntable immersed in water, the instrument beams ultrasonic waves into the specimen undergoing inspection, sequence of the test being automatic. Beams reflected by structural discontinuities, which may be defects, are logged on a circular chart which becomes a record to aid inter-



Make sure — get genuine Bristol replacement parts

for your Bristol instrument

• Let's face it. The best instrument parts wear out. We make ours as accurate, as dependable and as long-lived as possible. But, eventually, some parts must be replaced. And when that time comes, it doesn't make sense to risk your original investment in a Bristol instrument by buying a doubtful replacement part.

All Bristol parts are designed, engineered and inspected to fit a specific instrument, to perform with complete accuracy even under the most rugged service conditions.

You wanted the best — and you got it, when you bought Bristol. So don't take chances when it comes to replacement parts. Only genuine Bristol parts are made to original Bristol blueprints; naturally they'll fit better and perform better — longer. Remember, Bristol knows Bristol best. Write to the Bristol Company, 113 Bristol Road, Waterbury 20, Conn.

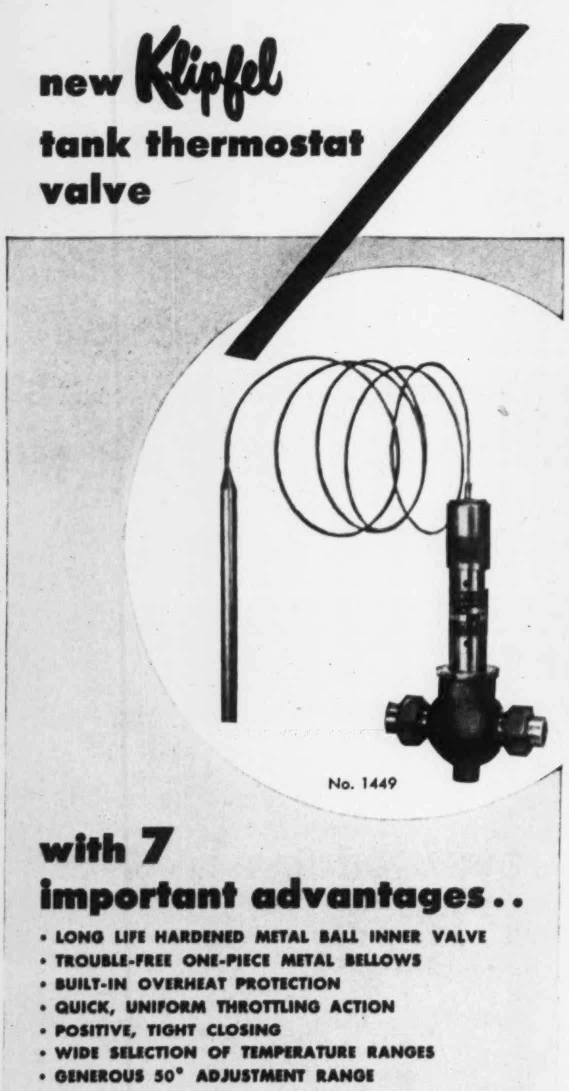
4.20

BRISTOL

Points the Way in Human-Engineered Instrumentation

AUTOMATIC CONTROLLING, RECORDING AND TELEMETERING INSTRUMENTS

For more information circle **18** on inquiry card.



new Klipfel tank thermostat valve

No. 1449

with 7 important advantages..

- LONG LIFE HARDENED METAL BALL INNER VALVE
- TROUBLE-FREE ONE-PIECE METAL BELLOWS
- BUILT-IN OVERHEAT PROTECTION
- QUICK, UNIFORM THROTTLING ACTION
- POSITIVE, TIGHT CLOSING
- WIDE SELECTION OF TEMPERATURE RANGES
- GENEROUS 50° ADJUSTMENT RANGE

For dependable, low-cost temperature control, select this NEW Klipfel Thermostatic Valve . . . perfected to give the service you want with accuracy, dependability and minimum maintenance. Write for complete details or request literature from your supply house or Klipfel Distributor, listed in the classified telephone directory.

NEW 2 MORE MONEY-SAVING KLIPFEL CONTROLS

No. 1549 — Pilot-operated Temperature Regulating Valve . . . sensitive, positive control for high pressure, larger sizes.

No. 1649 — Combination Temperature and Pressure Control . . . single main valve with temperature and pressure control saves cost and labor!

Trouble-Free Heart of the Valve

Rotating ball seats perfectly . . . is self-cleaning . . . gives streamlined flow!

Klipfel VALVES, INC.
1070 LINCOLN AVE.
HAMILTON, OHIO

Export Office—1010 Schaff Building, Philadelphia 2, Pa.

For more information circle 19 on inquiry card.

pretation and filing. Detection of defects in advance of machining can achieve obviously substantial economies.

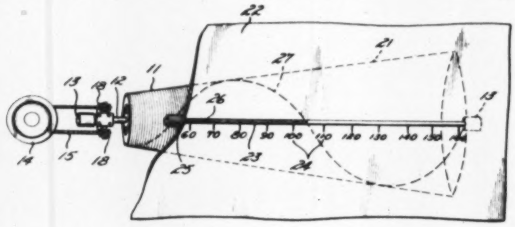
The complete installation comprises a scanning machine (left), recorder (center), control cabinet and electronic console (right), which is also a monitoring station. There are two accessory units—a punch for preparing a program-controlling tape, and a set-up table.

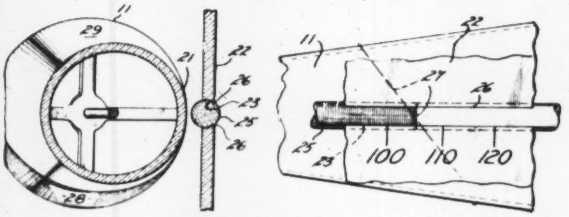
Computer Instruction

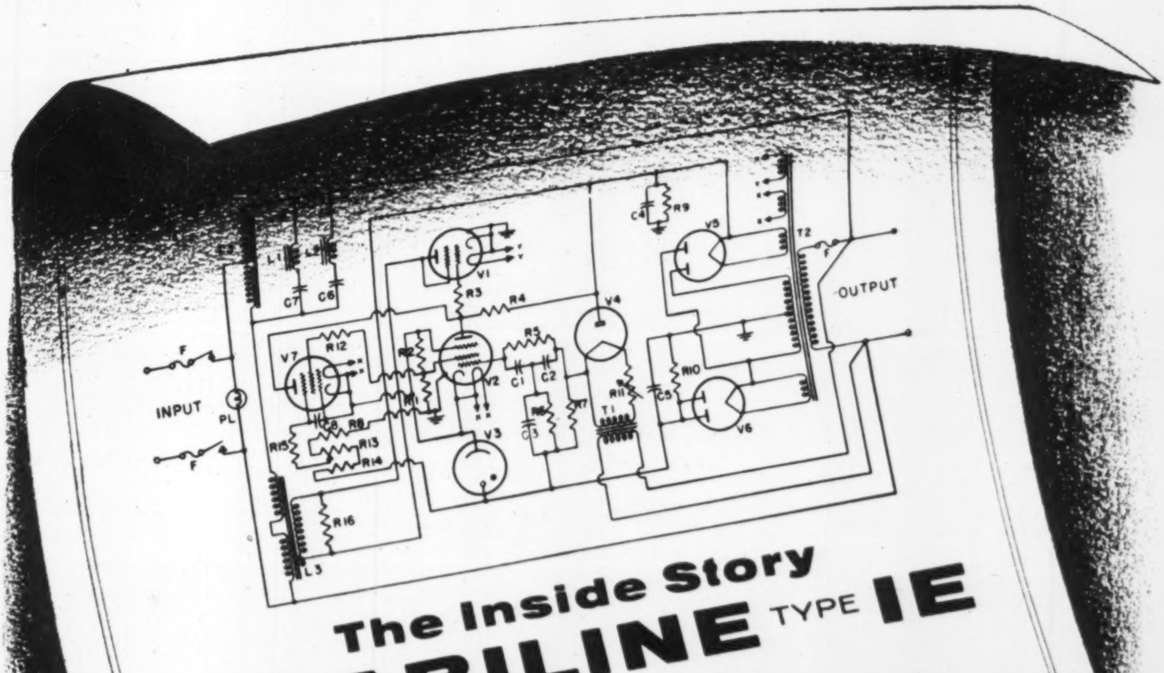
PASADENA, CALIF.—"College of Computer Knowledge" at ElectroData Corporation's Computing Center, Pasadena, California, acquaints customers, prospective users, and future industrial planners with fundamentals of electronic computation. Here ElectroData Computer control panel is demonstrated to coding class which is learning to translate business problems into computer language.

New Scale Indicator

LOS ANGELES, CALIF.—Patent 2,678,621, granted May 18, 1954 to Robert E. Proctor, 3163 Sawtelle Blvd., Los Angeles, provides simple effective means for obtaining a rectilinear scale indicator from helical line or ribbon marked on cylinder or conical surface. A cylindrical lens of convex cross-section refracts rays of light from the engraved inclined line so that the inclined line, when viewed through the lens, appears erect. The small portion of the outer rays that are not so refracted is hidden by lens-supporting structure so that only vertical line appears.

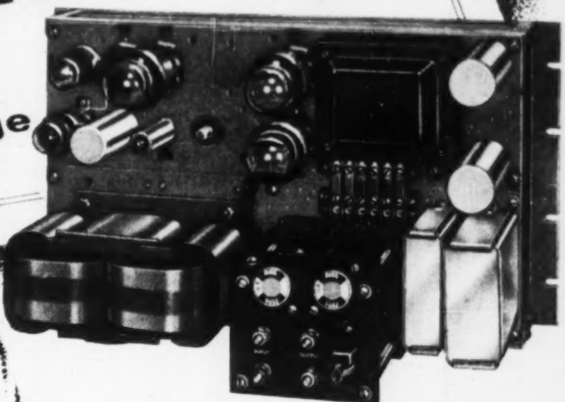






The Inside Story STABILINE TYPE IE

Instantaneous Electronic Automatic Voltage Regulators



STABILINE Type IE5101R. Rated 95-135 Volts, 60 cycles input; 115 volts, 1.0 KVA output.

- **Instantaneous Correction**
- **Excellent Regulation and Stabilization**
- **Minimum Waveform Distortion**
- **Wide Input Range**
- **Adjustable Output Voltage**
- **Insensitivity to Frequency Changes**

The circuit diagram shows how the error detector, the amplifier and power control circuit are combined in a STABILINE Type IE to deliver stabilized and regulated a-c voltage.

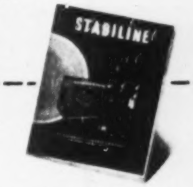
You will find a combination of circuit simplicity and mechanical ruggedness in STABILINE Automatic Voltage Regulators Type IE. Send us the details of your specific requirements or use the coupon below. Numerous models are offered in capacities from 0.25 to 5.0 KVA.

Visit Superior Electric's Mobile Display when it visits your area.

THE SUPERIOR ELECTRIC COMPANY

712 Clarke Ave., Bristol, Conn.

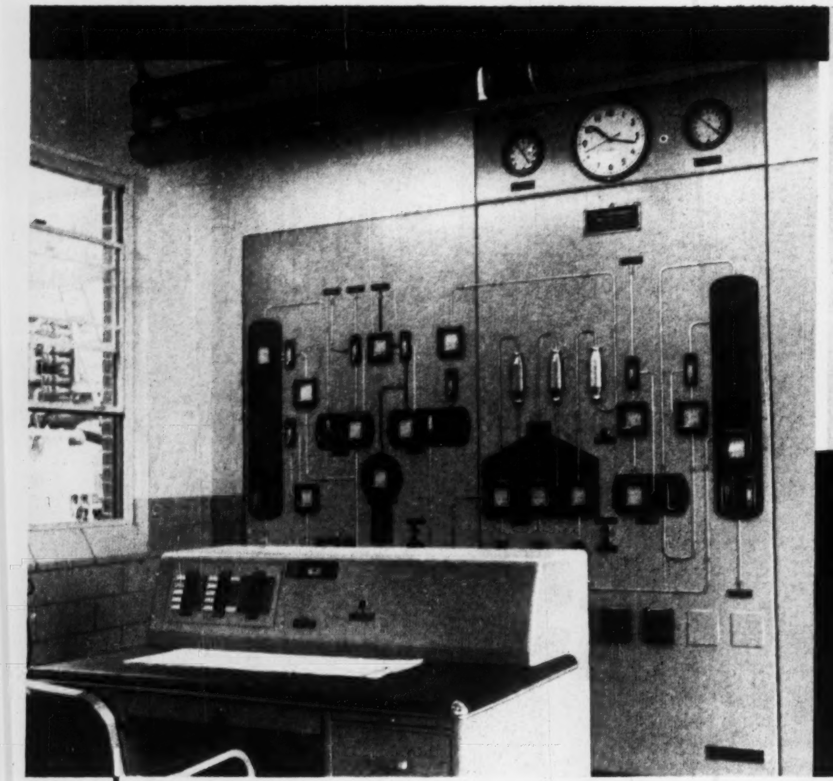
Manufacturers of: Powerstat Variable Transformers • Stabiline Automatic Voltage Regulators • Voltbox A-C Power Supplies • Powerstat Light Dimming Equipment • Varicell D-C Power Supplies • Superior 5-Way Binding Posts

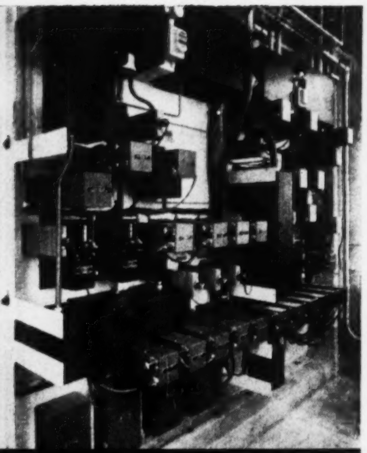


THE SUPERIOR ELECTRIC CO.
712 Clarke Ave., Bristol, Conn.
Please send Bulletin S351 on STABILINE Automatic Voltage Regulators.

Name...
Position...
Company Name...
Company Address...
City...Zone.....State...

For more information circle **20** on inquiry card.



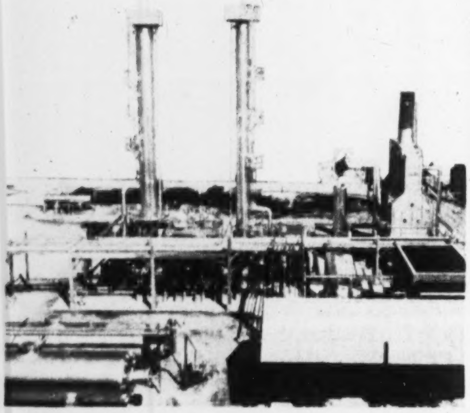


▲ BACK OF AUTRONIC graphic control panel. Note simple electric wiring, absence of expensive-to-install tubing.

◀ AUTRONIC CONTROL offers infinite sensitivity due to elimination of moving parts which are affected by friction. Reproducibility is .1 percent.

Swartwout Autronic System

featured in first complete refinery unit with electronic controls



PLATFORMING AREA of Rock Island Refinery, Indianapolis, Ind., first refinery in the U. S. to be controlled electronically. From l to r, splitter and stabilizer columns, reactors, reactor charge heater. *Photos: Courtesy Universal Oil Products Company.*

Pioneering is not new to Rock Island Refining Corp., the first refinery in the world to install a graphic panel. And now Rock Island scores another "first"—a complete refining unit instrumented and controlled by electronics, the revolutionary step forward in sensitive, precise process control.

For this history-making installation, Universal Oil Products Co. designed and engineered a Platforming unit to produce motor fuel blending component. UOP's instrument department engineered the installation of Swartwout's electronic Autronic Control System.

The Autronic System worked perfectly from the beginning. Only 3 hours after startup, the unit was completely "lined-out" and operating smoothly. The Swartwout Autronic Control System results in better control because of increased sensitivity of electric impulses . . increases reliability of operation in cold weather by eliminating freeze-ups . . . eliminates pneumatic tubing racks thus reducing installation costs and problems concerned with startup and maintenance.

Swartwout *Autronic* **CONTROL SYSTEM**

THE SWARTWOUT COMPANY • 18511 EUCLID AVENUE • CLEVELAND 12 • OHIO

For more information circle **21** on inquiry card.

VOLTS
A.C.
Weston

new additions

to this comprehensive line of

MODERN PRECISION PORTABLES

WESTON 901 LINE

D-C

- Voltmeters
- Volt-Ammeters
- Ammeters
- Milliammeters

A-C

- Voltmeters
- **8 Range Voltmeters** *
- Ammeters
- **7 Range Ammeters** *
- Milliammeters

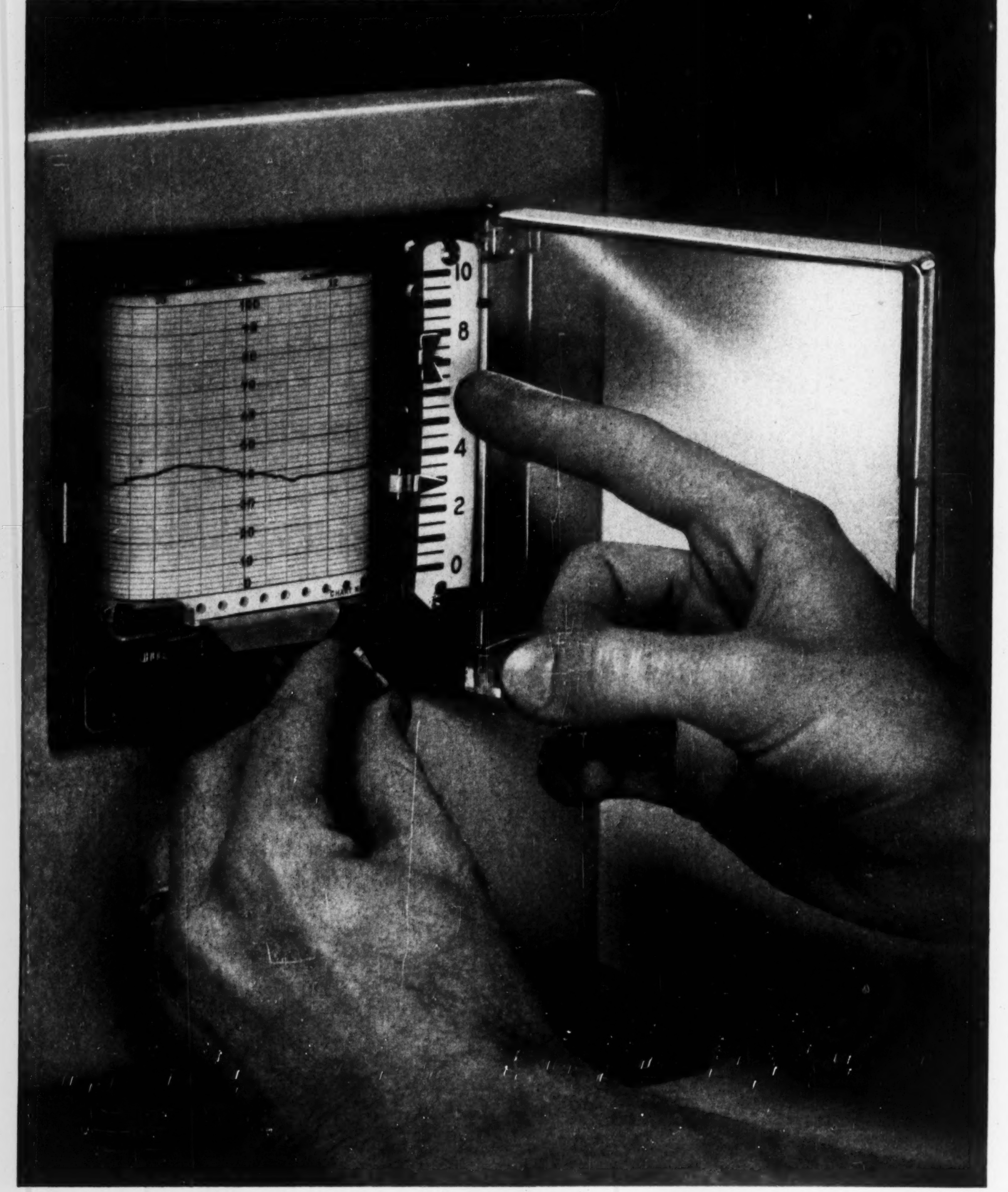
A-C and D-C single-phase Wattmeters *

Providing unequaled scale visibility due to wrap-around windows, the same rated accuracy of 0.5% and the same efficient shielding of all other instruments in this famous line, these three new additions make the 901 group the most comprehensive line of precision portables available. Complete specifications and prices available in bulletin form, or from the WESTON representative in your vicinity . . . WESTON Electrical Instrument Corporation, 614 Frelinghuysen Avenue, Newark 5, New Jersey.

WESTON
Instruments

For more information circle **22** on inquiry card.

. . . WHAT'S NEW AT BRISTOL . . .



BRISTOL'S "HUMAN-ENGINEERED" METAGRAPHIC RECORDER, with its easy-to-read scale, high-visibility fluorescent pointers and shadow-proof door has earned a reputation as the "biggest miniature in the industry". There's no switching necessary to get a reading of the control valve position. The continuous valve-position indication, separate from set-point indication, gives continuous data on control valve position and process level. The high-precision, two-stage, no-drift set-point regulator has high-capacity (3 scfm) output for fast manual control in emergencies.

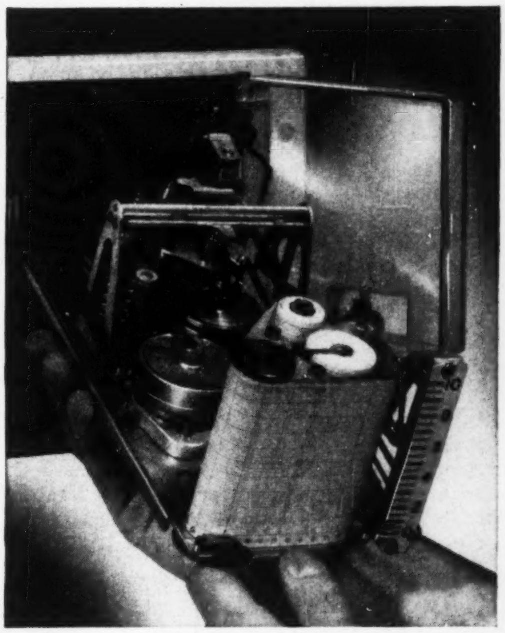
For more information circle **23** on inquiry card.

Instrument men call Bristol's METAGRAPHIC Recorder

"... the biggest little instrument in the industry"

Sounds contradictory, but it's true. Take a look at one of our new METAGRAPHICS mounted on a panel board alongside of other instruments. The Bristol unit stands out — seems bigger than the rest — although chances are it's actually smaller (5"x5½"). The answer is that the Bristol instruments have been *"human-engineered"*, making them easy to read, and clearly visible at greater distances.

To meet the increasing need for miniature instruments, we didn't simply scale down one of our larger recorders, we designed a completely new unit, creating a smaller instrument with all the advantages of the large one. In other words, the new METAGRAPHIC is a "big" little recorder.



TRUE PLUG-IN SERVICE is a big advantage to the operating man. If trouble is suspected in an instrument, the doubtful unit can be removed and a spare plugged in in a matter of seconds, with no interruption in the process operation, no loss of air, no loss of control.

"Human-engineered" METAGRAPHIC records pressure, temperature, vacuum, flow, differential pressure, and liquid level

Here are some of the advantages of the air-operated Metagraphic Recorders:

SIMPLICITY . . . fewer moving parts, fewer adjustments, and less service required. Range changes can be made in seconds.

CONTINUOUS VALVE-POSITION INDICATION . . . on same instrument scale as set-point scale, gives continuous data on control valve position—makes "bumpless" transfer possible simply by matching pointer positions — no need to read actual scale values — minimizes reading errors — speeds operations.

TRUE PLUG-IN SERVICE . . . provides great savings in installation costs. Cases can be ordered and installed before selecting range and type of control. Instruments can be plugged in later or interchanged at will. This adds up to a big advantage to the process design engineer — he doesn't need to make decisions during the design stage that can't be easily changed later.

CONTINUOUS OPERATION . . . complete unit can be retracted for inking pen, and for set-point and zero adjustment without disturbing record or control.

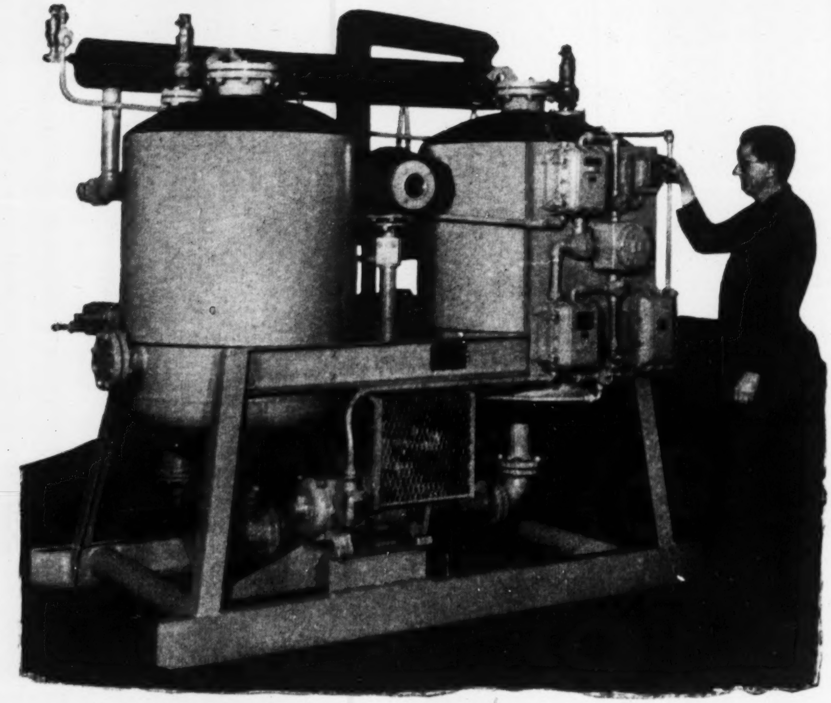
Get the whole story on the "human-engineered" METAGRAPHICS — how they can help you get more accurate measurements, faster and easier. Write us today. The Bristol Company, 113 Bristol Road, Waterbury 20, Conn.

6.4.3R

BRISTOL *POINTS THE WAY IN HUMAN-ENGINEERED INSTRUMENTATION*

AUTOMATIC CONTROLLING, RECORDING AND TELEMETERING INSTRUMENTS

For more information circle **23** on inquiry card.



Fully automatic instrument air dryer . . . BY-type Lectrodryer

DRY AIR and how to get it...

Even on the most arid desert, air is wet! Elsewhere, it's wetter. Hence, if you need dry air, you must use machinery to get it.

A Lectrodryer* is an air drying machine. With it you can dry great volumes of air in a continuous flow to prescribed low dewpoints. You can reduce the moisture content of air to a stable constant!

Lectrodryer machines can drop air to dewpoints below −100°F . . . reduce relative humidity below 10%.

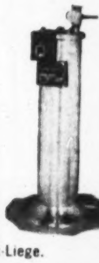
There's probably a Lectrodryer already built that meets your drying need. The largest (for a wind tunnel) dries three tons of air per minute to a dewpoint of −70° F. Smaller machines are preserving the interior of Navy ships of the "Mothball Fleet" by maintaining a constant relative humidity below 30%.

Besides air drying, there are Lectrodryers that dry many gases and organic liquids, handling pressures as high as 6000 psi.

If you use air, give some thought to drying it with a Lectrodryer. Write for *Because Moisture Isn't Pink,* a booklet describing Lectrodryers and how industries have used them. Request also, *The Moisture In Our Atmosphere,* a technical booklet on the nature, behavior and measurement of water vapor. Both are free! Pittsburgh Lectrodryer Corporation, 330 32nd Street, Pittsburgh 30, Pa.

LABORATORY LECTRODRYER

If your experimentation requires small quantities of dry air or other gases, a Laboratory Lectrodryer will help you greatly. Rated at 100 cubic feet per hour, these machines have in many cases provided the dryness in research that has led to large savings in production.



$155⁰⁰
F. O. B.
Pittsburgh

In England: Birlec, Limited, Tyburn Road, Erdington, Birmingham.
In France: Stein et Roubaix, 24 Rue Erlanger, Paris XVI.
In Belgium: S. A. Belge Stein et Roubaix, 320 Rue du Moulin, Bressoux-Liege.

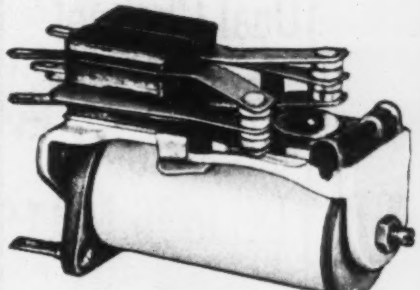
LECTRODRYERS DRY WITH ACTIVATED ALUMINAS

LECTRODRYER

* REGISTERED TRADEMARK U. S. PAT. OFF.

For more information circle **24** on inquiry card.

New variety of CLARE Type J Relay provides a power relay as sensitive and accurate as telephone-type relay



① Handles inrush current of 50 amperes for 50,000 operations—rating of 10 amperes, 27½ volts d-c.

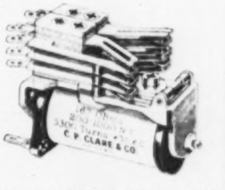
② Has exceeded 500,000 operations on motor load of 6 amperes—inrush current of 15 amperes—at 70,000 feet altitude.

The new CLARE Type J Relay has all the advantages of the small size, light weight and sturdy construction which makes the standard Type J Relay so popular with designers of electrical and electronic equipment.

Increased current carrying capacity is provided by the use of Code 18 (Silver) heavy duty contacts which are riveted to the springs. A combination of the standard Type J twin contacts and the new heavy duty contacts is also available.

Nominal rating of this new Type J Relay is: 10 amperes, 115 volts a-c (resistive); 10 amperes, 27½ volts d-c. The relay is 2¼" long, 1⅛" wide and 1⅜" high with two Form C contacts.

Long life and increased adjustment stability is provided by a new hinge-type armature. The new heavy-duty yoke has a stainless steel pivot pin with a large bearing surface which turns in precisely reamed bearings of nonferrous material.



Standard Type J Relay with independent twin contacts

Type JV Video Relay for high frequency currents

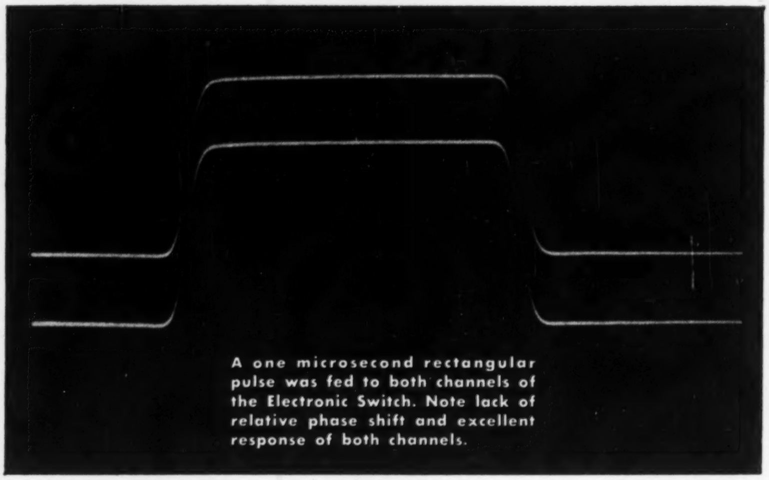
For complete information write for CLARE *Bulletin No. 119. For information on other variations of the Type J Relay send for our Engineering Data Book. Address: C. P. Clare & Co., 3101 West Pratt Blvd., Chicago 45, Illinois. In Canada: Canadian Line Materials Ltd., Toronto 13. Cable Address:* CLARELAY.

For more information circle **25** on inquiry card.

CLARE
RELAYS

FIRST
in the industrial field

Convert to Dual Channel Operation in the Range of DC to 15 MC



A one microsecond rectangular pulse was fed to both channels of the Electronic Switch. Note lack of relative phase shift and excellent response of both channels.

...using any Single-Channel Oscillograph with the

NEW DU MONT TYPE 330 ELECTRONIC SWITCH

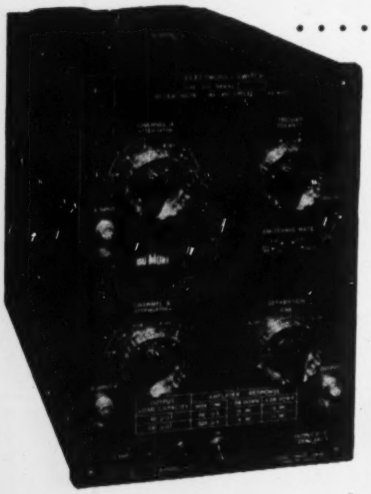
The new Du Mont Type 330 Electronic Switch is a self-contained accessory for oscillography that permits . . .

1. Converting *any* single-beam oscillograph into a dual-channel instrument.
2. Adding a channel to any multi-channel instrument.
3. As a chopper, converting an a-c oscillograph for d-c measurement.

Within the range of DC to 15 MC, the Type 330 is limited only by the characteristics of the cathode-ray oscillograph being used.

This is the answer to those studies requiring comparison between two or more functions. Maximum time shift between the channels of the Type 330 is within one millimicrosecond. Both channels may be adjusted for unity gain making it a simple matter to superimpose two phenomena for very precise time, phase or amplitude comparison.

Three free-running switching rates, 1KC, 10KC and 100KC, or triggered operation allow selection for best presentation on the cathode-ray oscillograph. The Type 330 can be connected into a test setup or disconnected as the need arises.



MAJOR SPECIFICATIONS

SIGNAL CHANNELS

I. Sinusoidal Frequency Response: with an output load of 60 uuf, either channel, flat to d.c. and down not more than 3 db at 15 mc.

II. Amplifier Rise Time: with external load of 60 uuf, no greater than 0.022 usec.

III. Variable Attenuator: Each channel has two series stepped attenuators with attenuation ratios of 1, 2, 4, 10, 20, 40, 100, 200, and 400; accuracy of attenuators ± 2%.

IV. Output: Level is zero volts d.c. with no signal or positioning voltage; positioning controls provide ±1 volt of d.c. positioning voltage.

SWITCHING

I. Recurrent: Free-running, fixed frequencies of approximately 1 KC, 10 KC and 100 KC; Triggered, rate may be triggered at 0 to 100 KC rates.

PRICE $295

WRITE FOR COMPLETE INFORMATION

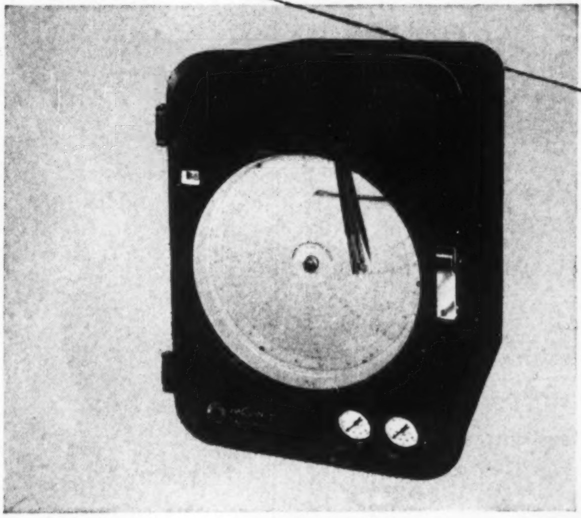
DU MONT

ALLEN B. DU MONT LABORATORIES, INC.
INSTRUMENT DIVISION
760 BLOOMFIELD AVENUE • CLIFTON, N. J.

For more information circle **26** on inquiry card.

HAGAN

Ring Balance Meter *beats the high cost of* Permanent Pressure Loss!



It works out like this:

Using an Expensive Primary Element . . . 10% of 100″ full scale differential is *10″ PPL*

Using a Low Cost Primary Element . . . 50% of 6″ full scale differential is *only 3″ PPL*

The Hagan Ring Balance Meter is particularly adapted for accurate operation at full scale differentials as low as 1″ WC, with *any* type of primary element. In many applications, by choosing a low cost, low differential element, with a PPL of 50% or more, and measuring the flow with a Ring Balance Meter, the actual permanent pressure loss is low. In the example shown above, *it is only a third of the actual PPL* sustained with a high cost, high differential primary element. Here is positive, long range economy . . . lower pumping costs result from reduced horsepower requirement.

This is an example of how Hagan experience and engineering skill can reduce costs. Hagan engineers will be glad to recommend the most economical solution to your metering problem.

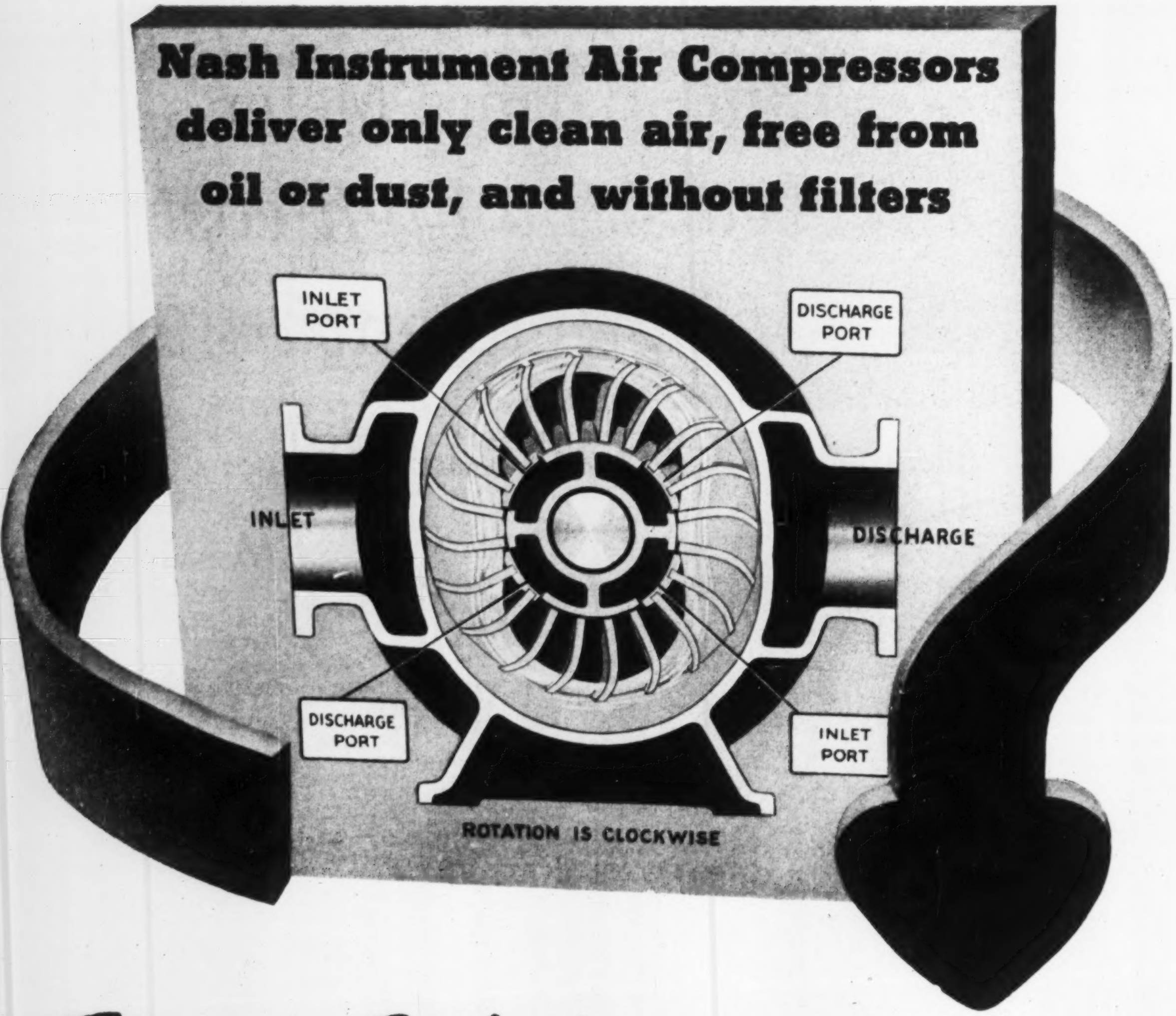
HAGAN
HALL
BUROMIN
CALGON

HAGAN CORPORATION
HAGAN BUILDING **PITTSBURGH 30, PENNSYLVANIA**

Boiler Combustion Control Systems, Ring Balance Flow and Pressure Instruments . . . Metallurgical Furnace Control Systems . . . Control Systems for Automotive and Aeronautical Testing Facilities

For more information circle **27** on inquiry card.

Nash Instrument Air Compressors deliver only clean air, free from oil or dust, and without filters



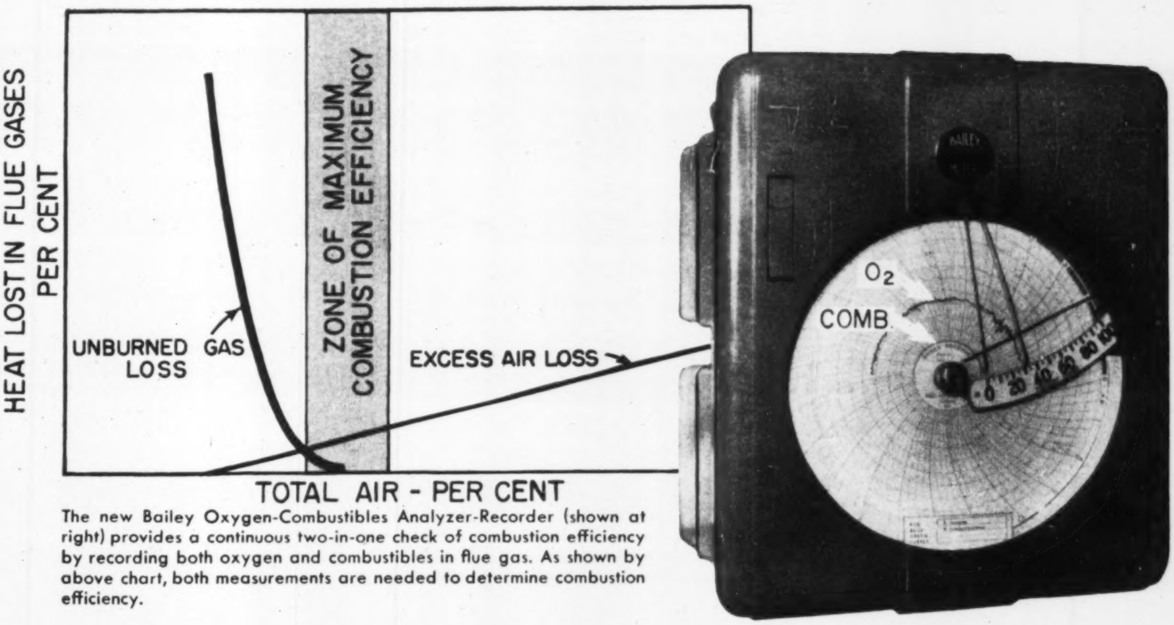
Here is Why!

You can dispense with oil filters and dust filters when you install ®Nash® Clean Air Compressors. You can save the cost of maintaining these devices. You can greatly reduce instrument maintenance costs. For the Nash employs no internal lubrication, therefore no troublesome oil is in the delivered air. Moreover, air from a Nash is thoroughly washed and cooled as it passes thru the pump. Dust in the plant atmosphere, even fly ash, is immediately removed.

®Nash® Clean Air Compressors are simple, with only one moving element. No valves, gears, pistons, sliding vanes, or other enemies of long life and constant performance complicate a Nash. No aftercoolers are needed. You will find it profitable to investigate these pumps, now.

No oil filters.
No dust filters.
No internal lubrication to contaminate air handled.
No internal wearing parts.
No valves, pistons, or vanes.
Non-pulsating pressure.
Original performance constant over a long pump life.
Low maintenance cost.

NASH ENGINEERING COMPANY
370 WILSON, SO. NORWALK, CONN.



The new Bailey Oxygen-Combustibles Analyzer-Recorder (shown at right) provides a continuous two-in-one check of combustion efficiency by recording both oxygen and combustibles in flue gas. As shown by above chart, both measurements are needed to determine combustion efficiency.

BAILEY announces . . . New 2 in 1 way to measure Combustion Efficiency

The new Bailey Oxygen-Combustibles Analyzer-Recorder gives you a continuing double check on combustion economy. It's fast response measures and records:

1. **Excess air**—regardless of the fuel or combinations of fuels being burned.
2. **The mixing efficiency of your fuel-burning equipment**—by indicating the amount of combustibles in your flue gas, resulting from incomplete mixing of fuel and air.

Combustion efficiency depends upon fuel-air ratio. Too much fuel can be even more costly than too much air. And because of the interdependence of these two factors, no control that measures only one of them can give you complete protection.

Now, for the first time, you can check *both* with a *single* fast acting instrument, using the new Bailey Oxygen-Combustibles Analyzer-Recorder for industrial furnaces, kilns, heaters and boilers.

Fuel economy improves as excess air is reduced—until unburned fuel begins to show up in the flue gas. When this happens, combustion efficiency drops off sharply if there are further decreases in the air-fuel ratio. That's why combustion gases must be analyzed for *both* oxygen and combustibles to get a true indication of efficiency—and that is why Bailey coordinates both measurements on the same chart, to show when excess air may be reduced safely without danger of greater losses from unburned gases.

The Bailey Oxygen-Combustibles Analyzer is an approved combustion safeguard.

Ask your local Bailey engineer for suggestions on application. Equipment details in Product Specifications E65-1 and E12-5. P31-1

BAILEY METERS

BAILEY METER COMPANY

1041 IVANHOE ROAD • CLEVELAND 10, OHIO

INSTRUMENTS AND CONTROLS

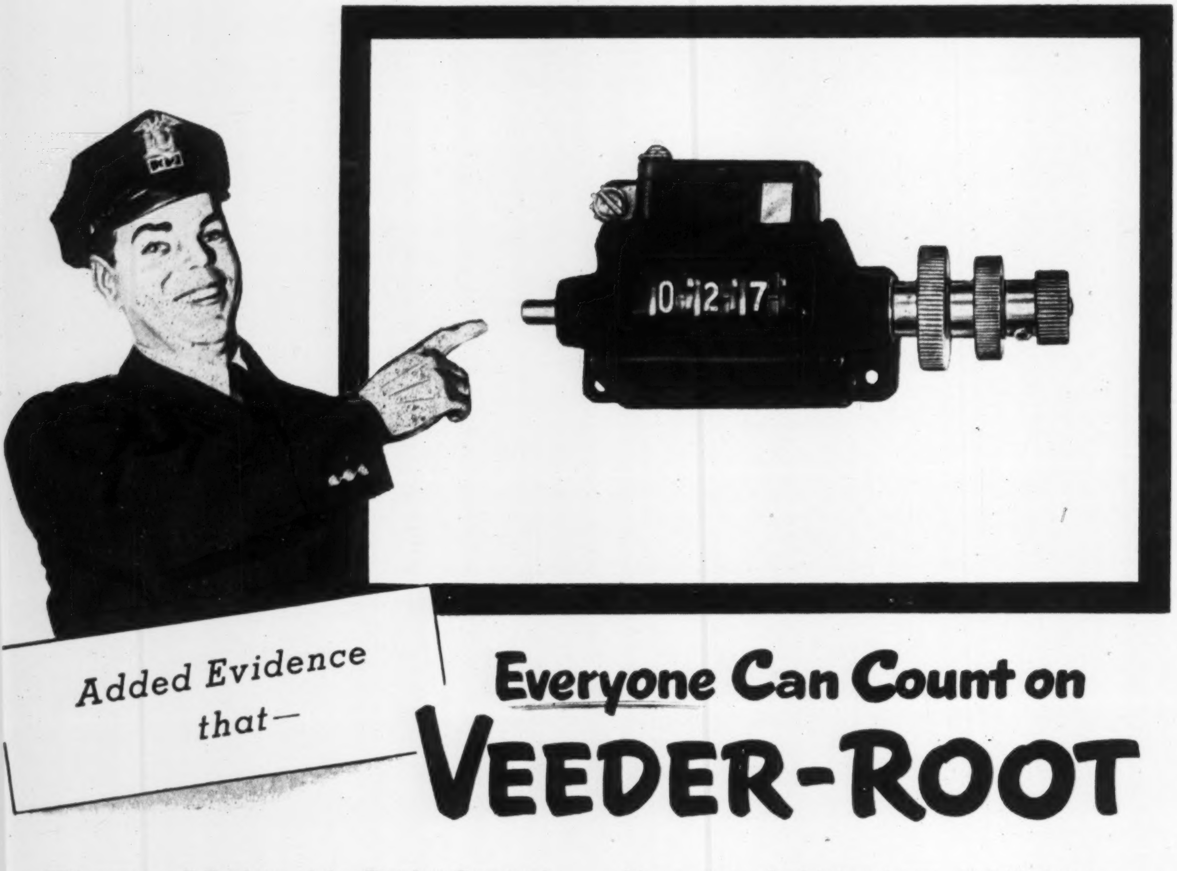
For Power And Process

For more information circle **28** on inquiry card.

Here's a New

"TRAFFIC COP"

for short high-speed runs



Added Evidence that—

Everyone Can Count on

VEEDER-ROOT

This new small Predetermining Ratchet Counter is set for any run up to 1,000 counts, pieces or other units by the three knurled setting knobs. Then it subtracts to zero, and at that point actuates a contact to light a light, ring a bell or stop the machine. Compact and easy to reset, this counter makes an attractive new selling feature when built into a machine as a standard integral part. And it's just one of scores of standard and special Veeder-Root Counters for every mechanical and electrical application in any field from atomics to automation. What would *you* like to count? Let Veeder-Root figure out how to do it. Write:

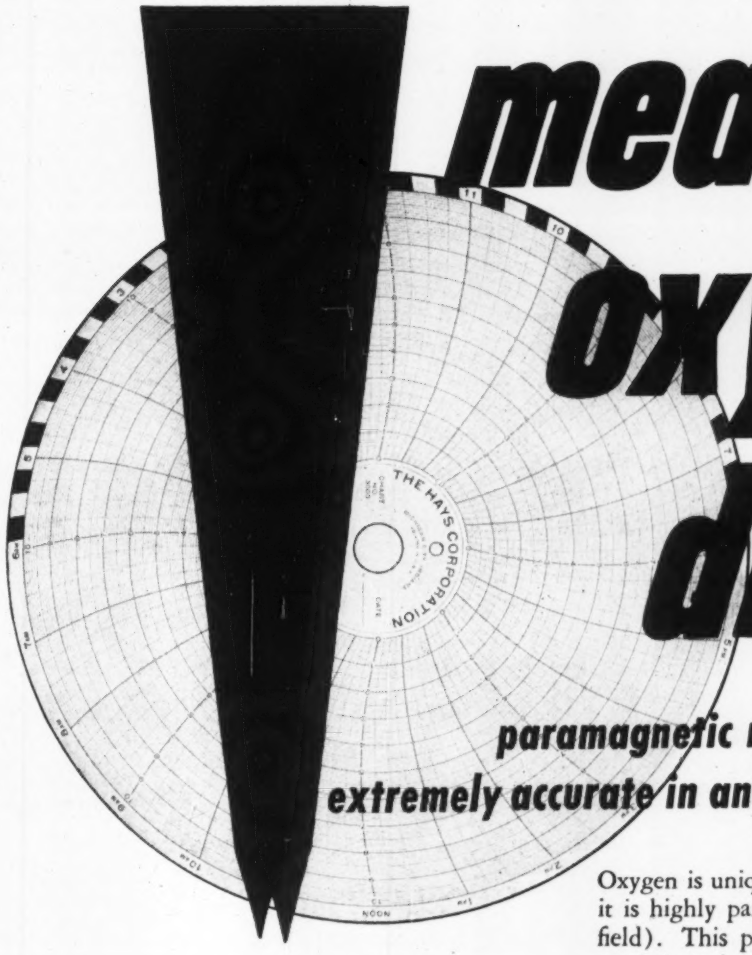
VEEDER-ROOT INCORPORATED
HARTFORD 2, CONNECTICUT

Chicago 6, Ill. • New York 19, N. Y. • Greenville, S. C.
Montreal 2, Canada • Dundee, Scotland
Offices and Agents in Principal Cities

® **"The Name that Counts"**

For more information circle **29** on inquiry card.

measure oxygen direct



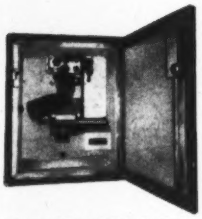
paramagnetic method of measurement extremely accurate in analyzing industrial gases

Oxygen is unique among other common gases in that it is highly paramagnetic (attracted into a magnetic field). This property of oxygen is the basis of the operation of the Hays Magno-Therm Analyzer in the analysis of industrial gases.

application

Hundreds of companies are using the Hays Magno-Therm O_2 Analyzer and Recorder in applications from revivification of SO_2 removers in manufactured gas industry and regeneration of catalysts in oil refineries to mixing air with propane to get substitute fuel. Boiler plants use it as a combustion guide because it is the only means of getting an undistorted picture of excess air.

Write today for bulletin 52-829-56 and get complete details.



ANALYZER

Highly sensitive to changes in oxygen content.

Rapid response to changes in oxygen content.

No liquid or gaseous fuel required to be added to gas sample.

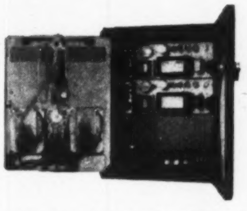
No chemicals required.

High accuracy maintained.

Not affected by wide variation in rate of flow of gas sample.

Rugged construction. No delicate or moving parts.

Easily installed — no special fittings required.



RECORDER

Self-balancing bridge circuit assures accurate, permanent calibration.

Electronic amplifier has no moving parts. High sensitivity. Rugged.

Immediate response—analyzer is continuously connected to recording pen drive motor.

As many as four analyses can be recorded on the same chart.

Range can be changed easily in the field.

Isolating transformer for each amplifier removes line interference from bridge circuit.

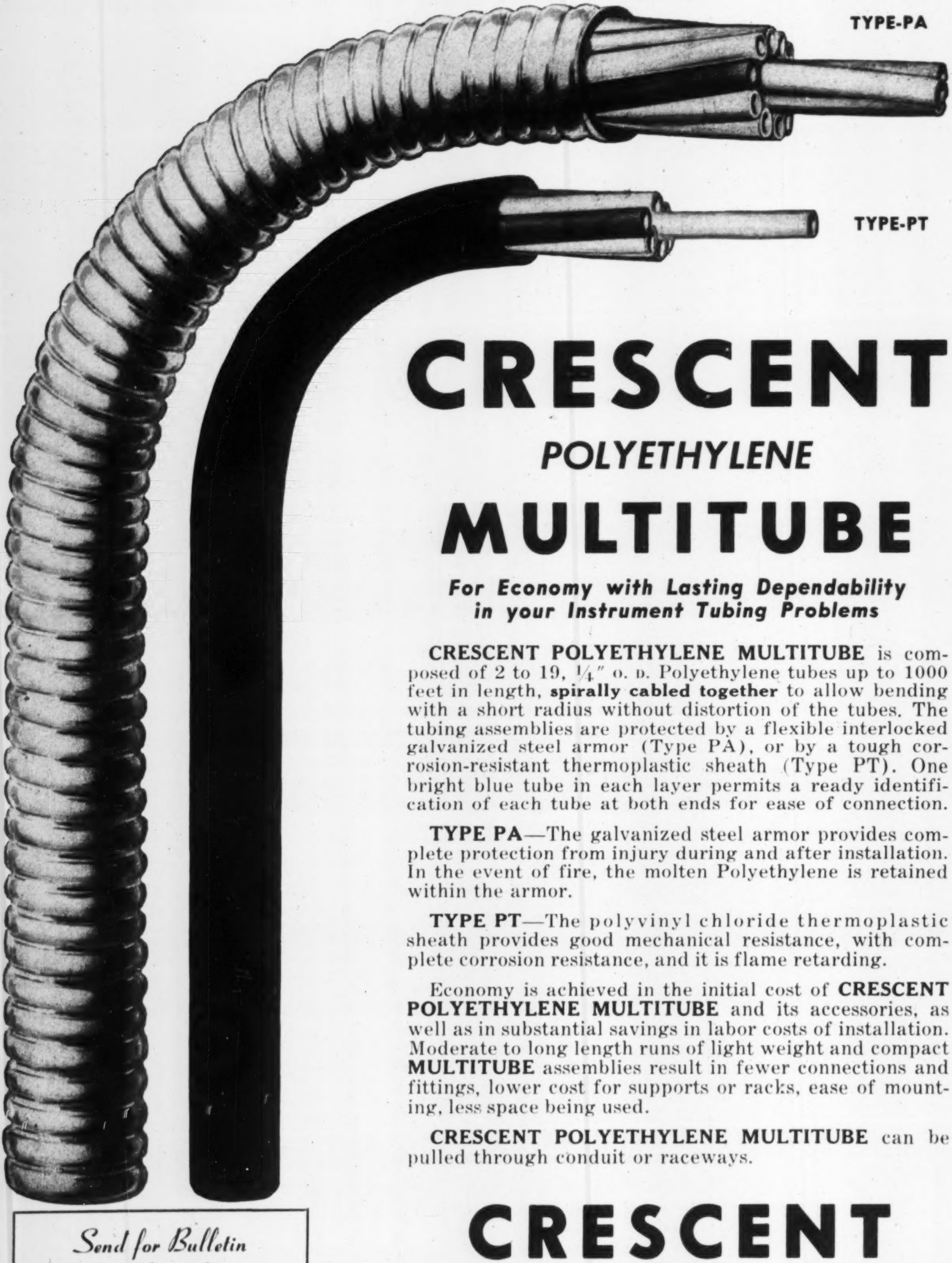
Extra slide wire available for control, remote indication—for recorder or contacts for alarm circuit.

Automatic Combustion Control
Boiler Panels • CO_2 Recorders
Veriflow Meters and Verifrol
Gas Analyzers • Draft Gages
Combustion Test Sets
Electronic Oxygen Recorders
Electronic Flowmeters
Electronic Feed Water Controls
Miniature Remote Indicators

THE hays CORPORATION

Michigan City 8, Indiana

For more information circle **30** on inquiry card.



CRESCENT

POLYETHYLENE

MULTITUBE

For Economy with Lasting Dependability in your Instrument Tubing Problems

CRESCENT POLYETHYLENE MULTITUBE is composed of 2 to 19, ¼″ O. D. Polyethylene tubes up to 1000 feet in length, **spirally cabled together** to allow bending with a short radius without distortion of the tubes. The tubing assemblies are protected by a flexible interlocked galvanized steel armor (Type PA), or by a tough corrosion-resistant thermoplastic sheath (Type PT). One bright blue tube in each layer permits a ready identification of each tube at both ends for ease of connection.

TYPE PA—The galvanized steel armor provides complete protection from injury during and after installation. In the event of fire, the molten Polyethylene is retained within the armor.

TYPE PT—The polyvinyl chloride thermoplastic sheath provides good mechanical resistance, with complete corrosion resistance, and it is flame retarding.

Economy is achieved in the initial cost of **CRESCENT POLYETHYLENE MULTITUBE** and its accessories, as well as in substantial savings in labor costs of installation. Moderate to long length runs of light weight and compact **MULTITUBE** assemblies result in fewer connections and fittings, lower cost for supports or racks, ease of mounting, less space being used.

CRESCENT POLYETHYLENE MULTITUBE can be pulled through conduit or raceways.

Send for Bulletin
giving complete information
and engineering data

CRESCENT

INSULATED WIRE & CABLE CO.
OLDEN & TAYLOR STS., TRENTON, NEW JERSEY

For more information circle **31** on inquiry card.

Here's why it pays to know

your HSM

HONEYWELL SUPPLIES MAN

HARRY SPONGBERG, Honeywell Supplies Man in the Chicago area, helps Chester Pickrell of the Crane Co. choose the most advantageous grade of Brown thermocouple wire to work with his *ElectroniK* instruments . . . and points out the quality features of Brown wire that spell long service and consistent precision of measurement.

Personal, specialized assistance by your HSM brings you the best in quality, economy and convenience for all your purchasing of pyrometer supplies. An individualized HSM Plan for your plant can save you money . . . simplify your inventory . . . speed your ordering.

Your local HSM will be glad to survey your requirements. Call him today . . . at your local Honeywell office . . . as near to you as your phone.

MINNEAPOLIS-HONEYWELL REGULATOR CO., *Industrial Division*, Wayne and Windrim Avenues, Philadelphia 44, Penna.

- **REFERENCE DATA:** Write for Pyrometer Supplies Buyers' Guide No. 100-5 . . . and for new booklet, "The HSM Plan."

H
HONEYWELL

MINNEAPOLIS
Honeywell
BROWN INSTRUMENTS

First in Controls

For more information circle 32 on inquiry card.

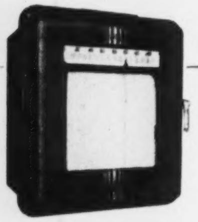
WORKING ON TOP SECRET PROJECTS?

Call on L&N's Experience in Automatic Measurements

Whether your project involves jet engines or atomic energy—guided missiles or radar—component performance tests or automatic weather stations . . . you may well want the latest data on electronic recorders for research and testing. Without revealing any secrets, you can easily give us the facts which will produce a recorder exactly suited to your needs.

More than 350 types of measuring circuits are available, each designed for a specific application in research or production. A few of the specialized L&N recorders using these circuits for research applications are listed below.

These high performance, low maintenance instruments can be calibrated in temperature F or C, millivolts, pH, load, conductivity, rpm, etc., according to the type and form of information you require. If your top secret measuring problems can be reduced to basic electrical quantities, just tell us the instrument's range and the type of transducer used . . . nothing more. Consult your nearest L&N Office, or write to Leeds & Northrup Company, 4955 Stenton Ave., Philadelphia 44, Pa.



Speedomax Polar Recorder . . . automatically plots distribution curves of antenna or sonar patterns, light distribution patterns, computer outputs, etc. See Data Sheet E-ND46(5).

Speedomax Millivolt Recorders . . . widely used wherever it is possible to reduce the measured quantity to millivolts . . . are available in a complete line of instruments. See L&N Sales Offices.

Speedomax AZAR Recorder . . . an adjustable zero, adjustable range instrument . . . is used to record the results of tests covering various ranges. See Data Sheet E-ND46(4).

Speedomax 160 Point Recorder Assembly . . . uses banks of 20 auxiliary stepping switches to scan and record as many as 160 temperatures in 11 minutes. See Data Sheet ND46(24).

Speedomax X-Y Recorder . . . plots a curve showing the relationship between any two interdependent variables. See Data Sheet E-ND46(1).

Speedomax X_1-X_2 Recorder . . . plots two electrical signals simultaneously against time on one chart. See Data Sheet E-ND46(3).

Speedomax High-Precision Temperature Recorder . . . plots resistance of platinum thermometers equivalent to a range of −260 to +500 C with an accuracy of ±0.01 C. See Folder ND46-33-240(1).

Packaged Control Systems . . . for complete measurement and control of reactors, test cells, etc. No publication available for this as they are tailored to your specific needs.

LEEDS LN NORTHRUP

instruments *automatic controls • furnaces*

For more information circle 33 on inquiry card.

Editorial...

Instruments **and AUTOMATION**

FIRST AUTOMATION EXPOSITION

INTENSE interest has been generated at all levels of our society about "automation." This interest culminated in a highly successful and interesting First International Automation Exposition, held Nov. 29 to Dec. 2 in New York City. As expected, top-management representatives of most major industrial producers came to see the new developments in the field of automatic control. But, for the first time, representatives of finance, labor, news services and educational institutions came from all parts of the world to monitor an industrial exposition. They came because of the social and economic implications of automatic control for all segments of society. They came to see what devices comprise the field of automation, what applications have been found for these devices, and how they might affect our way of life.

They saw the most advanced techniques for automatic control of plant, factory, and office operations. All new techniques were represented—(1) digital techniques, including analog-to-digital conversion, and direct digitized readout and printout of process variables, (2) automatic machine-tool control, (3) centralized automatic process control, (4) electronic computers and data processors, (5) telemetering techniques, and (6) servomechanisms and components. The newest features of each of these fields were displayed:

Computers

Highlights of the Exposition were the Computer Clinic and the complete coverage of electronic computers. Computing equipments of Austin (special-purpose computers), Donner Scientific (small analog), Bendix (digital), Electronic Associates (analog), Goodyear (analog), International Business Machines (data systems) and Remington Rand (data systems) were featured. A wealth of perspective and application data was delivered via the Computer Clinic, which was successful in combining the exhibited devices with lectures and demonstrations on applications. The Clinic attracted registrants from all phases of industry and finance—and from all parts of the U. S. These practical lectures will be made available via a COMPUTER HANDBOOK, now in preparation.

Digital Techniques

Digital techniques are growing in importance. On display were the new digitized VTVM's of Electro-Instruments and Hycon; the counters of Post Machinery, Hewlett-Packard, and Atomic Instrument Co.; the analog-to-digital converters of Giannini and Victor Adding Machine Co.; the pulse equipment of Electro-Pulse; the digital tape handlers of Potter; the decade counting switches of Kellogg. Potter also disclosed the first American-made photoelectric punched-paper-tape handler.

Plant and Factory Control

Many interesting devices for automatic control of machine tools and plant operations were exhibited by Russell T. Gilman, Federal Products, Hillyer Instrument, Sheffield, Zenith Electric, George Scherr, Standard Electronics, Taft-Pierce, Wilson Mechanical Instrument Div. of American Chain & Cable, Kybernetes, Techniflex, Uehling, Balteau, Infra Electronic, and others. A complete centralized process-control graphic panel was shown by Panellit. Contact-meter relays were exhibited by Assembly Products and Larson Instrument.

Telemetering

Closely associated with automatic control is telemetering, which permits remote control. Versatile telemetering systems of time-impulse duration, audio-frequency shift and other techniques for multiplexing were presented by Femco, Hammarlund, Instruments, Inc., Kleinschmidt, Radio Frequency Labs., and Teletype Corp.

Servo pickups, motors, gears, components, amplifiers, clutches, and systems were exhibited by Farrand Optical, Feedback Controls, Infra Electronic, Doelcam, Crawford Fitting, Dynamic Gear, Instrument Components, Falstrom, Parker Fittings, PIC Design, and others.

Recording is an important and basic part of automation. Oscillographs, inkless recorders, and tape recorders were exhibited by Brush, Heat-Timer, Larson, Magnecord, Davies Labs., and Potter.

Also significant were the new *electric valve operators* of Techniflex, the *ITV* of General Precision and Kay-Lab, the *air systems* of Nash and Trincor, the *power supplies* of Beta Electric, Sorensen, and Superior Electric; the *optical devices* of Karl Heitz and Zeiss-Jena.

The First Automation Exposition did much to clarify the field of automation. It defined its devices, functions and applications. It presented the modern techniques for information accumulation, reduction, and use to the end of volume production with maximum efficiency. Both the AUTOMATION HANDBOOK* (containing technical data on all exhibited products) and the COMPUTER HANDBOOK will be in great demand in the interim until the 2nd Automation Exposition, Chicago, Nov. 14-17, 1955.

*The AUTOMATION HANDBOOK is now available from The Instruments Publishing Co., 845 Ridge Ave., Pittsburgh 12, Pa. Price: $2.00.

ISSUES

The Counter Reads 0 0 3 2 4

and thereby registers the end of the twenty-seventh year of *Instruments and Automation's* service to users of measurement and control devices—service to

THE UNITED STATES OF AMERICA

The entire staff of *Instruments and Automation* wishes you

Season's Greetings

The Month's NEW INSTRUMENTS

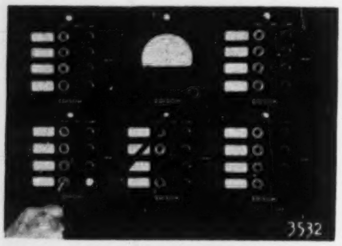
In this department we report each month new devices for measurement, inspection, testing, computing, metering and automatic control—in the form of concise technical descriptions.

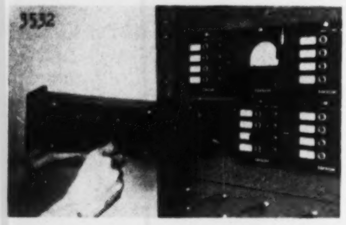
FOR FURTHER INFORMATION USE THE POSTAGE-FREE ORDER CARD ON PAGE 1995

PROCESS CONTROL AND GENERAL-PURPOSE INSTRUMENTATION

Multi-point Monitoring and Protection System

New "Omniguard" is said to be "undoubtedly the simplest and most flexible temperature monitoring system ever offered to all branches of industry." Monitor units and indicator can be mounted close to equipment to be protected, and master alarm signal can be carried through a single pair of copper wires to a control room at a distance. Exclusive feature is that system monitors all points simultaneously without scanning.—*Instrument Div., Thomas A. Edison, Inc., West Orange, N. J.*

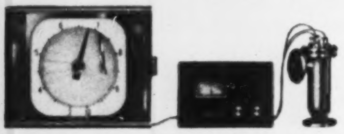




For more information circle **201** on inquiry card.

pH Instrumentation

New complete systems for pH recording and control comprise a Bristol "Electronic Dynamaster Potentiometer" recorder or controller, a Beckman "Model W" amplifier, electrode assemblies in either flow or immersion types, and a variety of final control elements for addition of gaseous, liquid, solid, or slurried reagents.—*The Bristol Co., Waterbury 20, Conn.*



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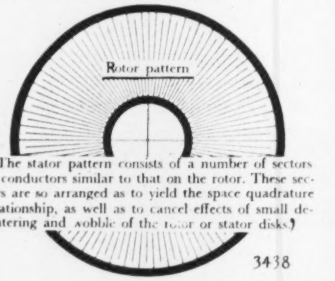
Angle-transmission System

New "Inductosyn" multipole synchro system is said to be "of almost unbelievable accuracy" as a shaft-position transmission system. Principal innovation: instead of pairs of coils and magnet faces as inductive-coupling pairs, new system uses pairs of radial pole patterns etched on 3-inch glass disks, from master disks ruled on extreme-precision dividing machine. Among uses: machine-tool control with accuracy of 0.0001 in. translational or 5 sec. rotational; backlash-free gear ratio; low-inertia speed changer; electromechanical dividing head; digitizer. Number of poles can be 64 or 128 for binary-code uses, 72 or 144 for degree systems, 54 or 108 for military (27-speed) systems, or as requested.—*Farrand Optical Co., Inc., Bronx Blvd & E. 238th St., New York 70, N. Y.*



(The stator pattern consists of a number of sectors of conductors similar to that on the rotor. These sectors are so arranged as to yield the space quadrature relationship, as well as to cancel effects of small decentering and wobble of the rotor or stator disks.)

For more information circle **203** on inquiry card.

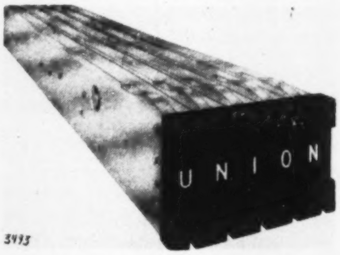
Dissolved-oxygen Analyzer

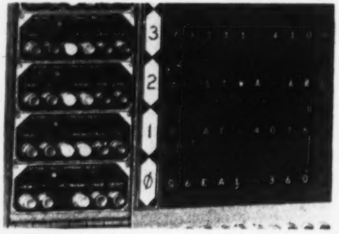
New "Model 1A3B" continuously measures dissolved oxygen in fluid process streams for municipal and industrial applications, such as sewage treatment, water treatment, chemicals, food processes, etc. By employing a new and improved method of stripping in combination with maker's "F3" paramagnetic oxygen analyzer, a measurement specific for dissolved oxygen in fluids is made. Analyzer is adjusted to read zero on an oxygen-free scrubbing gas, and is then used to measure volume percent of oxygen in gas issuing from stripper column, thereby indicating percent saturation of oxygen in the liquid. Can provide readings in ppm. dissolved oxygen.—*Arnold O. Beckman, Inc., 1020 Mission St., South Pasadena, Calif.*

For more information circle **204** on inquiry card.

Indicators for Data Display and Transfer

New "Union Indicators" stem from program instigated by Air Navigation Development Board for solution of air traffic administration problems. System can handle information at rate of more than a thousand words a minute; can operate on any transmitting medium—electrical, radio, microwave, carrier, radar, etc.—*Union Switch & Signal div. Westinghouse Air Brake Co., Pittsburgh 18, Pa.*

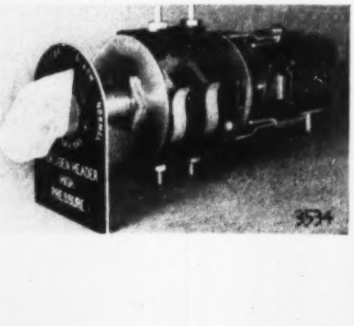




For more information circle **205** on inquiry card.

Alarm Device

New "Electro-Larm" protects equipment or process against abnormal operating conditions. Four indications, given by position of indicator key which also contains a neon glow lamp, are "normal," "alarm," "pending," "clear." Indicator key is illuminated in last three positions; audible signal

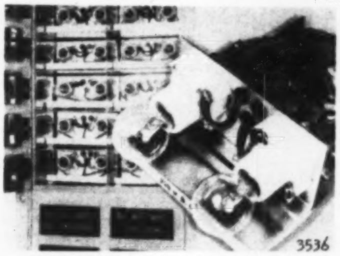


is sounded during "alarm" and "clear."—*Electro Devices Inc., 4025 Easton Ave., St. Louis 13, Mo.*

For more information circle **206** on inquiry card.

Annunciator

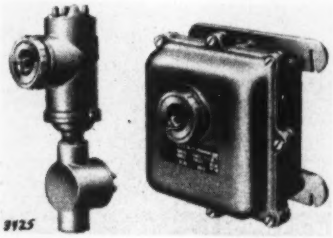
New "Electro-Pane" heavy-duty window type of annunciator features a sequence of four different indications accomplished by use of three sealed mercury switches. Four different indications are distinguished by different colors of illuminated nameplate through use of plastic color filters and diffusing prism which insures nameplate lighting.—*Electro Devices Inc., 4025 Easton Ave., St. Louis 13, Mo.*



For more information circle **207** on inquiry card.

Photoelectric Control

New explosion-proof photoelectric system comprises "Type EPL 243 Condulet" light source and "Type EPA 342 Condulet" light-sensitive control relay assembly. Light source housing features lens focal limits adjustable from infinity to 6 in. from lens. Receiver has lens, phototube, thyratron, electronic amplifier and load control relay.—*Crouse-Hinds Co., Wolf & 7th North Streets, Syracuse, N. Y.*



For more information circle **208** on inquiry card.

Telemetering System

New "ElectroSyn Pressure and Temperature Measuring System" utilizes a high-resolution linear-output

NORWOOD
50
100
150
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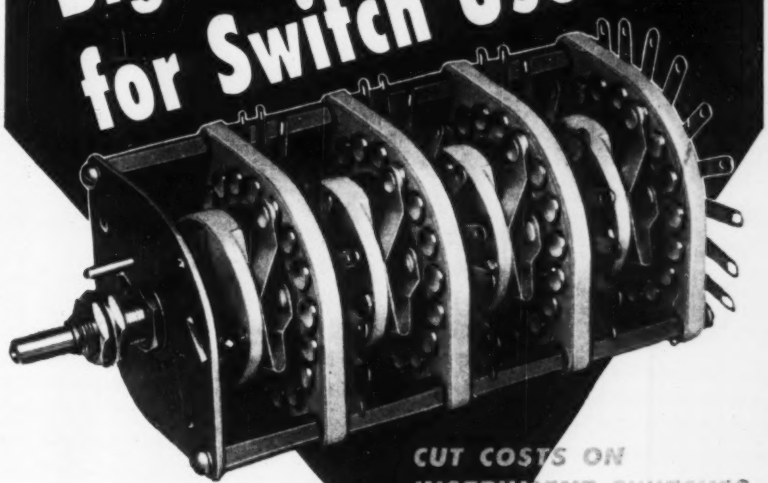
3425



Big News for Switch Users

CUT COSTS ON INSTRUMENT SWITCHES

SHALLCROSS "12000 SERIES" ... OVER 275 TYPES FROM STOCK

New Shallcross "12000 Series" Oval Ceramic Switches offer "custom-built" quality — without the delay and cost of specials.

With only a few basic interchangeable parts, constantly stocked by Shallcross, over 1000 different switch types can be quickly assembled. Delivery is immediate. Your specifications are matched exactly.

The use of solid silver contacts and collector rings, low-loss steatite decks, and silver plated beryllium-copper wiper pressure springs assures uniformly low contact resistance and exceptional durability for a wide variety of instrument switching applications.

For complete information on "12000 Series" Switches, write, wire, or phone for Shallcross Engineering Bulletin L-32 which catalogs 275 of the most popular types. SHALLCROSS MFG. CO., 510 Pusey Avenue, Collingdale, Pa.

Shallcross 12000 Series
Oval Ceramic Switches

NON-SHORTING ACTION—40° or 60° indexing
SHORTING ACTION—20° or 30° indexing
DETENT—Optional. Positive-acting star wheel type.
POLES PER DECK—1, 2, or 3
NUMBER OF DECKS—Up to 10 decks may be ganged.
ADJUSTABLE STOP—Available on order
SHAFT—Completely isolated
CONTACT RESISTANCE—0.0025 ohm, ±0.0002 ohm
RATINGS—110 v., 1a., 60 cy.-**nominal.** 2500 v., 60 cy.-**de-rated current.** 40 amps—**de-rated voltage.**

Complete specifications in Bulletin L-32.

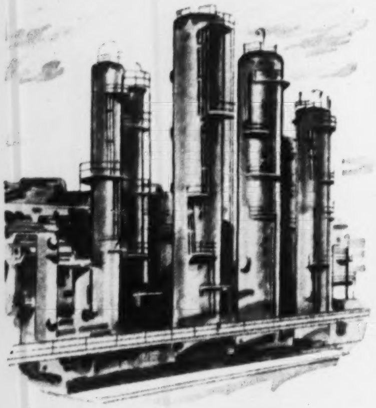
Our 25th Year **Shallcross**

For more information circle **34** on inquiry card.

DE LUXE MODEL

$49,000,000.00

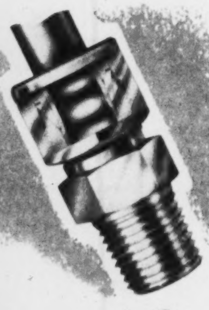
LEAK DETECTOR



While this leak-detecting device carries a $49,000,000.00 price tag, it is worth every penny of it! This device will not find leaks any faster than lower-priced models, but it will usually find more of them.

Leaks are expensive. Why not specify Swagelok Fittings and stop leaks before they happen?

Write for the Swagelok Catalog today. Address Department 113



Swagelok®

TUBE FITTINGS

BRASS • ALUMINUM • STEEL

STAINLESS STEEL • MONEL

CRAWFORD FITTING CO.

884 E 140th Street

Cleveland 10, Ohio

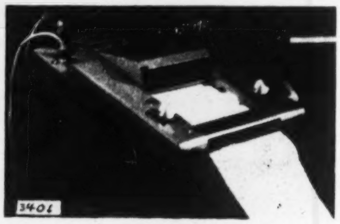
For more information circle **35** on inquiry card.

electromagnetic rotary transmitter, with Bourdon tube or bimetallic primary element, producing an electrical signal proportional to element's deflection; and long-scale indicator on remotely-located control panel. Long-range transmission can be accomplished using line or microwave facilities. Among features of system: high output without amplification; stability unaffected by either lateral or longitudinal vibration and line voltage changes.—*Controls Div., Control Engineering Corp.*, 934 *Washington St., Norwood, Mass.*

For more information circle **209** on inquiry card.

Thirty-channel Recorder

New time-operation recorder can monitor up to 30 machines; utilizes "Alfax" electrosensitive paper: when electricity flows, there is a mark; no electricity, no mark. Current to activate styluses is picked up by tiny switches mounted on machines (or doors, windows, drawers, etc.) by bolt, thumbtack, tape, etc. Recorder has two fixed paper speeds and paper drive shaft is brought out so that it can be driven at any speed desired. All units are plug-in.—*Alden Electronic and Impulse Recording Equipment Co., Westboro, Mass.*



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For more information circle **210** on inquiry card.

Tank-gaging System

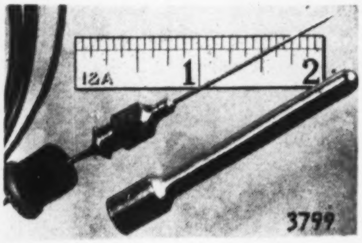
New "Gilbarco Electronic Gauge," said to be designed for maintained accuracy of 1/16-in. in refineries, terminals and tank farms, uses no float or sonic mechanism; features a servomotor which raises and lowers a sensing element as liquid level rises or falls. Tip of a metal probe in sensing element is the only part which touches the liquid. Any petroleum product at temperatures up to 175 F. can be measured. Among claims: "100% more accurate than hand gauging or other automatic gauges." A new null-balance receiver (illustrated), obviates need for mechanical vibrators or choppers and permits use of uniform scales. Like the gage itself, it is positively operated by servomotors.—*Gilbert & Barker Mfg. Co., West Springfield, Mass.*

For more information circle **211** on inquiry card.

TEMPERATURE

Miniature Thermocouple

New "Model TC-1A" 0.035-in. O.D. stainless-steel-protected copper-Constantan assembly, for −70 to 250 F. range, has 0.25-second response time, is hermetically sealed and normally supplied with 8 ft. extension cable. Choice of needle or blunt point, and of 1½-in. or 2½-in. length.—*Medical-Electronics Development Co., P.O. Box* 443, *Great Neck, N. Y.*



For more information circle **212** on inquiry card.

Change-of-state Type 1-hp. Thermal Switch

New "Mini-Therm" is a normally-open non-repetitive switch (does not reset). Different available switching temperatures are obtained by changes in composition of thermosensitive chemical. When switching temperature is reached, center electrode instantly drops down and makes metal-to-metal contact. Current rating 5 amps. at 250 v. Available in switching temperatures from 150 to 400 F. in 25-deg. increments and 400 to 1000 F. in 50-deg. increments. Speed of response equals that of a bare thermocouple, but time-integral action or insensitiveness to brief heats can be obtained by special enclosure, etc. Many aircraft testing and industrial safety applications are obvious. Cost is said to be nominal.—*MiniTec*, 5423 *Delaware Ave., Los Angeles* 41, *Calif.*

For more information circle **213** on inquiry card.

Self-balancing Indicator

New self-balancing indicator, added to maker's line of temperature-meas-

uring instruments, can be connected to several hundred thermocouples or resistance bulbs through connector panels, toggle switches, or rotary switches. (If switches, separate case). Scale is 34 in. long; full-scale travel 4 seconds; 23 ranges; accuracy 0.25 percent; sensitivity 0.05 percent; practically immune to shock, vibration or electrical interference.—*Thermo Electric Co., Inc., Saddle River Township, Rochelle Park P.O., N. J.*

For more information circle **214** on inquiry card.

Dial Thermometer

New "No. 35-S" 3½-in. mercury-actuated dial thermometer features external calibration. Stainless steel case, with clear plastic face covering and gasket sealed to stainless steel back plate, can be rotated to any readable position. Actuation is direct-drive Bourdon. Bulb lengths 4, 6, 8 and 12 in. Fittings: separable sockets, union connections and flanged union. —*Palmer Thermometers, Inc.,* 2505 *Norwood Ave., Cincinnati* 12, *Ohio.*

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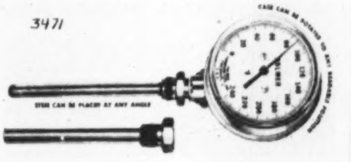
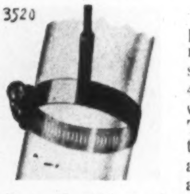


For more information circle **215** on inquiry card.

Pipe-clamp Thermocouples

New adjustable pipe clamp thermocouples for sizes from ⅜ to 4 in. are for use where immersion TCs are impractical or undesirable; for temperature readings on alloy, plastic or glass pipes not easily entered; installation and service without interrupting operations or flow; checking other devices; checking effectiveness of insulation; etc.—*Conax Corp.,* 4515 *Main St., Buffalo* 21, *N. Y.*

3520

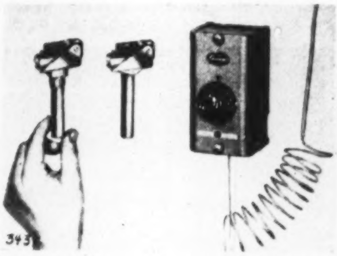


For more information circle **216** on inquiry card.

Snap-action Thermostat

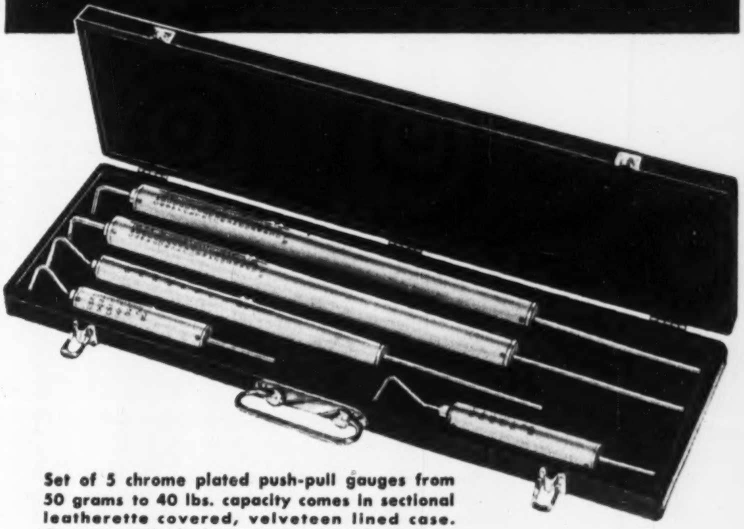
New liquid-filled snap-action 20-to-35-amp. thermostats are available in two models: Local bulb unit for use over an adjustable 50-to-300 F. range; and remote unit available in 50-to-250 F. and 150-to-550 F. ranges. Differential of 2 to 3 F. degrees is said to be "better than that of similar types of thermostats now available." —*Fenwal Inc., Ashland, Mass.*

343



For more information circle **217** on inquiry card.

where can you use
CHATILLON
instrument-type
PUSH-PULL GAUGES?

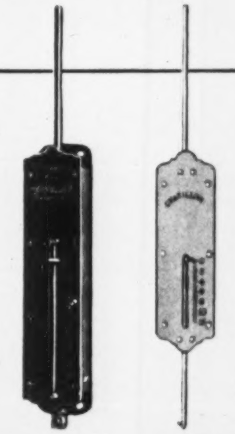


Set of 5 chrome plated push-pull gauges from 50 grams to 40 lbs. capacity comes in sectional leatherette covered, velveteen lined case. Gauges available in numerous combinations or separately.

How much pressure does it take to operate a push-button switch? How much tension to actuate a spring-loaded mechanism? What is the breaking point of a certain fibre? Chatillon instrument type push-pull gauges answer hundreds of such questions daily in laboratories, inspection areas and on assembly lines of leading manufacturers.

Calibrator and runner construction of these gauges is designed to give superior straight-line operation, maintained accuracy to within the minimum graduation. Precision calibrated springs of finest instrument steel give direct, instantaneous readings. *Universal design permits operation in any position!*

Ask yourself where you can apply Chatillon gauges or scales to improve your products or services. Chatillon's Engineering Department is ready to help you with adaptations or suggestions. *Write for bulletins.*



HEAVY DUTY GAUGES **UTILITY SCALES**

JOHN CHATILLON & SONS
87 CLIFF STREET, NEW YORK, N. Y.
Manufacturer of Precision Springs and Measuring Apparatus Since 1835

For more information circle **36** on inquiry card.

NEW INSTRUMENTS

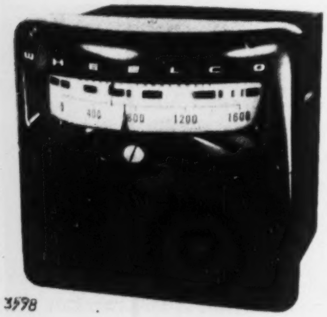
Temperature Controller

New "Model 297 Capacitrol" has been designed for new plastic machines, methods and materials; uses plug-in components; provides for flexible "on-the-job" adjustments. Thermocouple break protection can be supplied as an extra feature.—*Wheelco Instruments Div., Barber-Colman Co., Rockford, Illinois.*

For more information circle **218** on inquiry card.

Temperature Controller

New "Model 405 Capacitrol" is for continuous fuel-fired processes which require true proportional action; utilizes maker's "Electronic Control Principle"; incorporates means for manual "droop correction" and proportioning band adjustment; also thermocouple break protection.—*Wheelco Instruments Div., Barber-Colman Co., Rockford, Ill.*



For more information circle **219** on inquiry card.

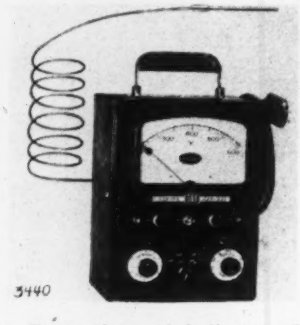
Thermoscopic Liquids

New "Tempilaq" suspensions for 425 and 475 F. have been added to maker's line of temperature-indicating materials. "Tempilaq" dries quickly, leaving a mat opaque coating which liquefies when temperature rating is reached. It adheres well to glass and other polished surfaces.—*Tempil Corp.*, 132 *W. 22nd St., New York* 11, *N. Y.*

For more information circle **220** on inquiry card.

Temperature Controller

New "Series 560" uses a thermistor primary element, is designed for range of 0 to 600 F.; available in industrial and portable laboratory models. Control accuracy (0.25 percent) is maintained even if indicating circuit should become inoperative, and is unaffected by moderate shock or vibration sufficient to cause temporary fluctuations of indicator. Control bandwidth can be increased from minimum value to any desired range. Instrument can be used either as a straight on-off controller or as a time-proportioning controller; can be calibrated in a few moments without standard cells or accessory devices. —*Fenwal Inc., Ashland, Mass.*

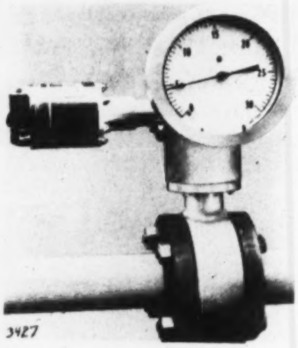


For more information circle **221** on inquiry card.

FLOW AND VOLUME

Flow-rate Indicator

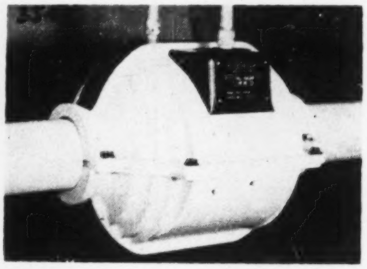
New variable-area assembly for continuously measuring flow rates of corrosive or non-corrosive gases and liquids combines installation ease of an orifice with linearity, rangeability, and low viscosity-sensitivity of variable-area types. Each assembly consists of: meter body; replaceable target-and-meter-range-insert primary elements; packless friction-free seal; mounting yoke; 6-in. dial indicator; and pressure differential adjustment screw. On yoke is provided a mounting pad for attachment of optional accessories such as Micro-switches; pneumatic or electrical position transmitters; or local controllers. Sizes are available for installation in pipe lines from ½ in. to 12 in.—*Devicengineering Co.* 1701 *Walnut St., Philadelphia* 3, *Penna.*



For more information circle **222** on inquiry card.

Electromagnetic Flowmeter

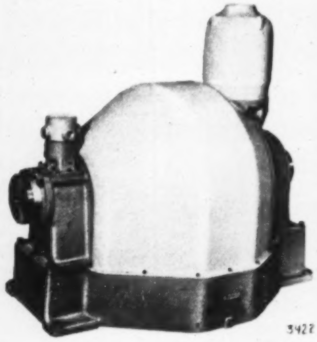
New electromagnetic flow-rate meter, designed for 2-in. to 8-in. flow lines, incorporates unique advantages of electromagnetic metering and is additionally rated for unlimited maximum flows, making practical a number of flow measurement applications impossible with ordinary metering equipment.—*The Foxboro Co., Foxboro, Mass.*



For more information circle **223** on inquiry card.

Mass Flow Meter

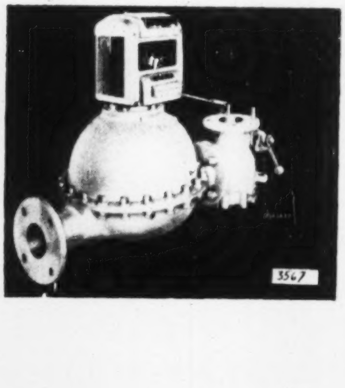
New "Gyro Mass Meter" utilizes principle whereby meter accuracy is independent of temperature, pressure, viscosity or volumetric flow rate; measures directly in pounds or tons; is easy to maintain and free from calibration drift.—*Controls Div., Control Engineering Corp.*, 934 *Washington St., Norwood, Mass.*

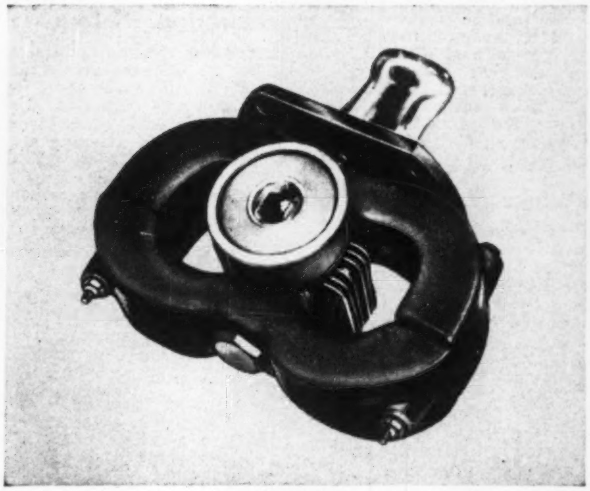


For more information circle **224** on inquiry card.

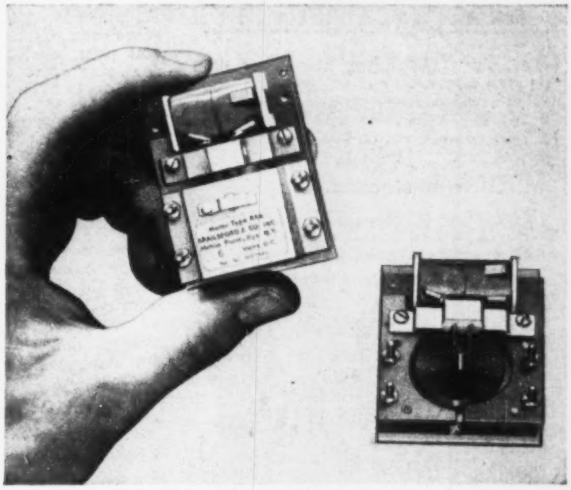
Batching Meter

New 3-in. "Auto-Stop" meter extends automatic control of batching and blending process liquid ingredients to flow-rates as high as 300 gpm. "Cushioned Auto-Stop" valve slows down rapid flow of liquid an instant





Search Radar Magnetron Tube. Two large Carboloy Alnico permanent magnets supply the electron beam control in this Raytheon magnetron. They help reduce size and weight, with no decrease in performance.



Miniature Electric Motor. Tiny, powerful Carboloy permanent magnet replaces wound electromagnet as rotor. The magnet's self-contained power supply reduces battery drain, requires less power.

Permanent magnets provide an economical way to convert electrical energy to mechanical motion

Carboloy® Alnico permanent magnets provide a low-cost means of simplifying design and reducing size in motors, radar magnetron tubes and hundreds of other products.

In the motor above, a tiny Carboloy permanent magnet rotor supplies the motor action; in the magnetron tube, two large Carboloy permanent magnets provide electron beam control. Both are examples of permanent magnets' inherent ability to convert electrical energy to mechanical motion. Thousands of other products utilize Carboloy permanent magnets' other basic functions (see below) . . . and realize substantial cost and design savings.

Permanent magnets supply a uniform source of stable, low-cost energy; help eliminate coils, wire and other operating parts. They are available cast, or sintered where closer tolerances and more complex shapes are required.

"Designing-in" permanent magnets will improve your product. Specially trained Carboloy Magnet Engineers will work with you in both design and application. Send coupon today, for complete information and technical literature.

Basic functions of permanent magnets

1. **Convert electrical energy to mechanical motion**
   - Eddy Current Braking
   - Instrument Action
   - Motor Action
   - Acoustic Action
   - Electron Beam Control
2. **Convert mechanical motion to electrical energy**
   - Generator Action
   - Magneto Action
   - Sound Pick-up
3. **Convert mechanical energy to thermal energy**
   - Control of Torque
4. **Mechanical Holding**
   - Snap Action
   - Separation
   - Holding and Lifting

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DEPARTMENT OF GENERAL ELECTRIC COMPANY
11155 E. 8 Mile Ave., Detroit 32, Michigan

"Carboloy" is the trademark for products of the Carboloy Department of General Electric Company

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I would like the following:

Information on permanent magnets in ____________

☐ Permanent Magnet Design Manual, PM-101
☐ Permanent Magnet Standard Stock Catalog, PM-100

Name ____________ Position ____________
Company ____________
Address ____________
City ____________ Zone ______ State ____________

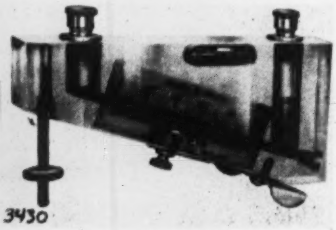
For more information circle **37** on inquiry card.

before it trips shut, providing extremely accurate cut-off with no hydraulic hammer.—*Neptune Meter Co., 19 W. 50th St., New York 20, N. Y.*

For more information circle **225** on inquiry card.

Blower-stream Gage

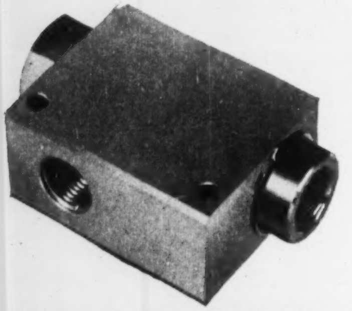
New "Gauge No. 172" determines blower speed in residential air-conditioning systems (out on the job) by measuring static pressure drop across evaporator; is also suitable to determine furnace draft, filter conditions, plemun pressure, etc.—*F. W. Dwyer Mfg. Co., 317 S. Western Ave., Chicago 12, Ill.*



For more information circle **226** on inquiry card.

Flow Regulator

New constant-flow regulator has automatic by-pass feature; maintains rate of flow regardless of variation in pressure or back pressure while simultaneously by-passing excess pump output at working pressure.—*Waterman Engineering Co., 725 Custer Ave., Evanston, Ill.*

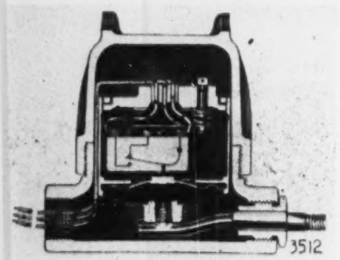


For more information circle **227** on inquiry card.

PRESSURE and VACUUM

P & V Switches

New explosion-proof pressure and vacuum switches repeat within 1 percent of setting. Housing is UL approved for Class I, group B, C and D; Class II, group E, F and G. Units cover range from 30 in. vacuum to 150 psig. Standard models available for single or dual settings; latter actuate two circuits, one a.c. and the other d.c. if desired. Units automatically reset.—*Barksdale Valves, 5125 Alcoa Ave., Los Angeles 58, Calif.*



For more information circle **228** on inquiry card.

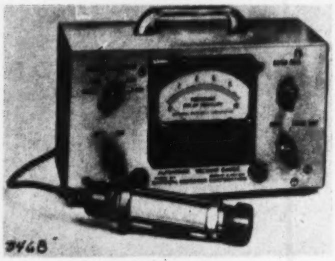
Pressure Pickups

New "Type B-1" of maker's "SR-4 pressure cells," specially designed for rough handling by pipe fitters and to meet the requirements of oil pipeline service, includes special features such as a heavy steel case and welded assembly, making cell rugged enough for pipe wrench tightening. Stronger signals are provided by 175 ohms resistance instead of customary 120 ohms. Eight sizes, from 100 to 2000 psi.—*Baldwin-Lima-Hamilton Corp., Philadelphia 42, Pa.*

For more information circle **229** on inquiry card.

A-c. Vacuum Gage

New "Model 517 Alphatron" vacuum gage, operates on a.c. Among other features: Six ranges from 1000 mm. to 0.1 micron Hg; linear scale; instantaneous response; connection for recorder, etc.; cannot be damaged by exposure to atmospheric pressure. —*Naresco Equipment Corp., 160 Charlemont St., Newton Highlands 61, Mass.*

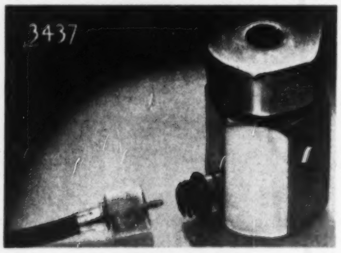


For more information circle **230** on inquiry card.

FORCE and WEIGHT

Force Pickup

New "Model 2101 Dynamic Force Gage" with 10-to-5000-cps. frequency range and 3-volt output permits new dynamic tests of servo systems, vibration-force generators, structures, etc. Piezoelectric principle is used for sensitivity to force changes only. Available for inputs of 15, 50, 100, 500, and 1000 lbs.—*Endevco Corp., 689 S. Fair Oaks Ave., Pasadena 2, Calif.*



For more information circle **231** on inquiry card.

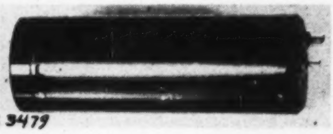
Acceleration Pickup

New acceleration pickup is capable of operating at temperatures from -65 to 550 F.; is said to be ideal for missile work and well suited for aircraft. Available in any range from ± 1 *G* to ± 50 *G* with damping normally furnished from 0.5 to 0.7 of critical; 300 to 20,000 ohms output for all *G* ranges; accurate 0.5 percent to 2 percent depending on *G* range and pot resistance.—*Pacific Scientific Co., 1430 Grande Vista Ave., Los Angeles 23, Calif.*

For more information circle **232** on inquiry card.

Acceleration Pickups

New linear acceleration pickups meet requirements of most recent military specs. "AT-LF" series covers range from ±.5 *G* to ±10 *G* with natural frequencies of 5 to 21 cps. "AT-HF" series ±1 *G* to ±50 *G* with natural frequencies from 10 to 98 cps. All fluid damped to 0.65 of critical.—*Rahm Instruments, Inc., 12 W. Broadway, New York 7, N. Y.*



For more information circle **233** on inquiry card.

Small-force Recorder

New "Universal Recording Balance" is specifically designed for observation and recording of small, rapidly-changing forces with respect to time. Among uses: observation, by direct weighing, of action of gases on metals at high temperatures; study of evaporation of solvent mixtures or solvents from paint film.—*The Sharples Corp., Research Laboratories, 424 W. 4th St., Bridgeport, Penna.*

Universal Recording Balance

For more information circle **234** on inquiry card.

Crane Scales

Three new small standard sizes of "SR-4 Crane Scales" are ½-ton, 1¼-ton, and 2½-ton. (Others are 5-ton, 12½-ton and 25-ton).—*Baldwin-Lima-Hamilton Corp., Philadelphia 42, Pa.*

For more information circle **235** on inquiry card.

Taking the "GUESS" out of Gauge Specifications

You'd be surprised how often those tough gauge problems can be solved easily by talking them over with one of USG's application engineers.

If your problem involves the handling of corrosive materials, extremes in temperatures and pressures, unique process application, or one of a hundred unknown factors, USG's wide engineering experience and facilities make possible tests under simulated operating conditions. This assures higher accuracy and maximum gauge life.

The test data available at USG may be of help to you in these and other gauge problems. Often, one of our over 200,000 stock gauges will meet your requirements . . . a real advantage from the standpoint of cost and availability. If, however, stock gauges do not serve your purpose, USG is in a position to make special gauges that will exactly fit your needs.

USG will be glad to help you solve any problem involving temperature and pressure indications. Why not call our District Office nearest you, or, send your problem directly to us at Sellersville.

UNITED STATES GAUGE

Gauge Headquarters
for over 50 years

United States Gauge, Division of American Machine and Metals, Inc., Sellersville, Penna.

For more information circle 38 on inquiry card.

USG'S RESEARCH LABORATORY SIMULATES OPERATING CONDITIONS FOR OPTIMUM GAUGE PERFORMANCE

To assure optimum operating results under new or changing process conditions, USG tests gauges in its Research Laboratory under simulated operating conditions. Annually, these USG tests save customers hundreds of thousands of dollars in greater operating performance and less down time, not to mention eliminating the need for more frequent gauge replacements.

Constant testing of materials and assemblies under all kinds of operating conditions is one reason why USG gauges are renowned for their enduring accuracy and dependability. USG assures this enduring accuracy and dependability in lot after lot by employing in its manufacture one of the most rigid quality control systems in the instrument industry.

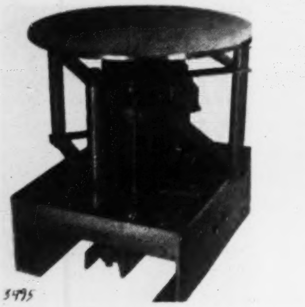
For more than 50 years USG has been designing and producing gauges for more original equipment manufacturers than any other instrument company in the world. With facilities economically integrated for large volume-quality controlled production, USG helps industry reduce its gauge costs by stocking the most complete line of gauge components to meet practically any pressure sensing or actuating need.

To assure immediate availability of standard gauges, USG maintains a large inventory of over 200,000 standard gauges in a wide variety of types, sizes and ranges.

Above, a portion of USG's Research Laboratory. Here constant testing of materials under customer operating conditions assures optimum performance and long gauge life.

Electric Platform Scale

New platform scale utilizing strain gage load cells and pneumatic tare weight permits inexpensive and accurate net weight measurement; is adaptable for either batch weighing or continuous process control. High accuracy is said to be result of a unique design of weighing structure using advanced techniques of flexural pivots to eliminate effects due to off-center loading.—*Weighing Components, Inc., 64 Fulmor Road, Hatboro, Penna.*



For more information circle **236** on inquiry card.

TIME and SPEED

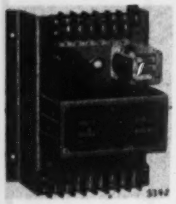
'Scope Display Timers

New oscilloscope display timers make possible detailed study of phenomena separated in time; provide ordinary 'scope with a time-base in the form of a 10-line raster containing accurate timing calibration markers (in effect, equivalent of a sweep magnification of X10 with no loss of detail). Two models: "101" has a raster range of 10 ms. to 0.1 sec. and a sweep range of 1 ms. to 10 ms.; "101A" has a raster range of 1 to 50 sec. and a sweep range of 0.1 to 5.0 sec.—*American Electronic Laboratories, Inc., 641 Arch St., Philadelphia 6, Penna.*

For more information circle **237** on inquiry card.

Time Delay Relay

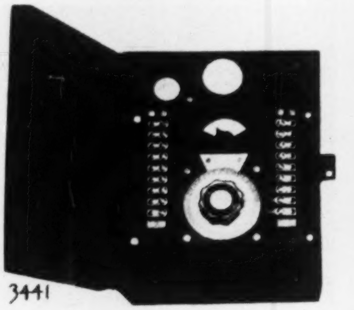
New "MEK-2110" is available in two timing ranges: 1.5 to 120 seconds or 0.75 to 60 seconds. D-p.d-t load contacts are rated at 5 amp., 115 v.ac. Choice of two sequences of operation. In Sequence A, load contacts are de-energized during reset and timing, and energized when timed out. In Sequence B, load contacts are energized during reset, de-energized during timing, and energized when timed out. Sequences are obtained by interchanging terminal strip connections.—*Machinery Electrification, Northboro, Mass.*



For more information circle **238** on inquiry card.

Electronic Timer

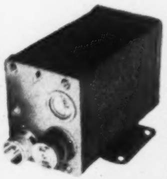
New "Model T2" for interval timing, timed delay, repeat cycling, programming or pulsing, maintains 1 percent accuracy over line voltage variations of 90-135 volts. Three time ranges: 0.1-1.0, 1-10, and 10-100 sec.; direct-reading time dial; two spdt load contacts with 8-amp. rating.—*Dep't H-1, Ferrara, Inc., 8106 W. Nine Mile Road, Oak Park 37, Mich.*



For more information circle **239** on inquiry card.

Adjustable-delay Relay

New time delay relays provide all features of hermetically-sealed units, also permit adjustment of delay period. Periods can be supplied from 2 seconds to 2 hours. Large calibrated dial, read through glass window, allows setting over an 8:1 range in small increments. Units meet military specs; available for operation on d-c. or a-c. power supplies.—*A. W. Haydon Co., Waterbury, Conn.*



For more information circle **240** on inquiry card.

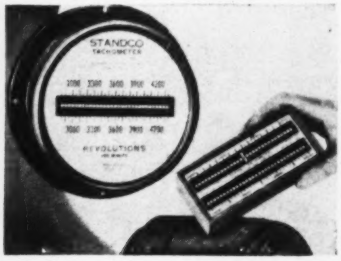
Time Data Printer

New Time-Data Printer can record (1) one or two sets of manually or remotely-entered data, (2) an entry identification number or symbol and (3) time-of-day when data are taken. Time is indicated to 0.01 minutes or in full seconds, is obtained internally from a synchronous motor. Arrangements for choice of data, identification and time are flexible.—*Engineering Dep't, Clary Multiplier Corp., San Gabriel, Calif.*

For more information circle **241** on inquiry card.

Tachometers

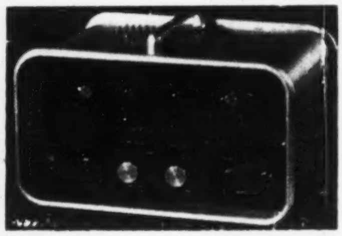
New "Standco" vibrating reed tachometers are available with single, double and triple rows of reeds in hundreds of ranges between 900 and 100,000 rpm. Hand types available in standard and dwarf size. Stationary types in 7½-in. round cases, and rectangular cases for permanent mounting on machines.—*Herman H. Sticht Co., Inc., 27 Park Pl., New York 7, N. Y.*



For more information circle **242** on inquiry card.

Frequency Counter

New "Model WE-110" electronic frequency meter and counter is a low-cost events-per-unit-time meter using recently developed glow transfer tubes, along with greatly simplified circuitry. Unusually high sensitivity (50 mv. rms.); frequency response (20 kc. guaranteed, 50 kc. possible) adequate for most applications. Designed to be used with low-output magnetic or photoelectric speed pickups, turbine, type flow pickups, vibration pickups, etc. Reference is 60-cps. line; time-bases 1 or 10 sec.—*Westport Electric, 149 Lomita St., El Segundo, Calif.*



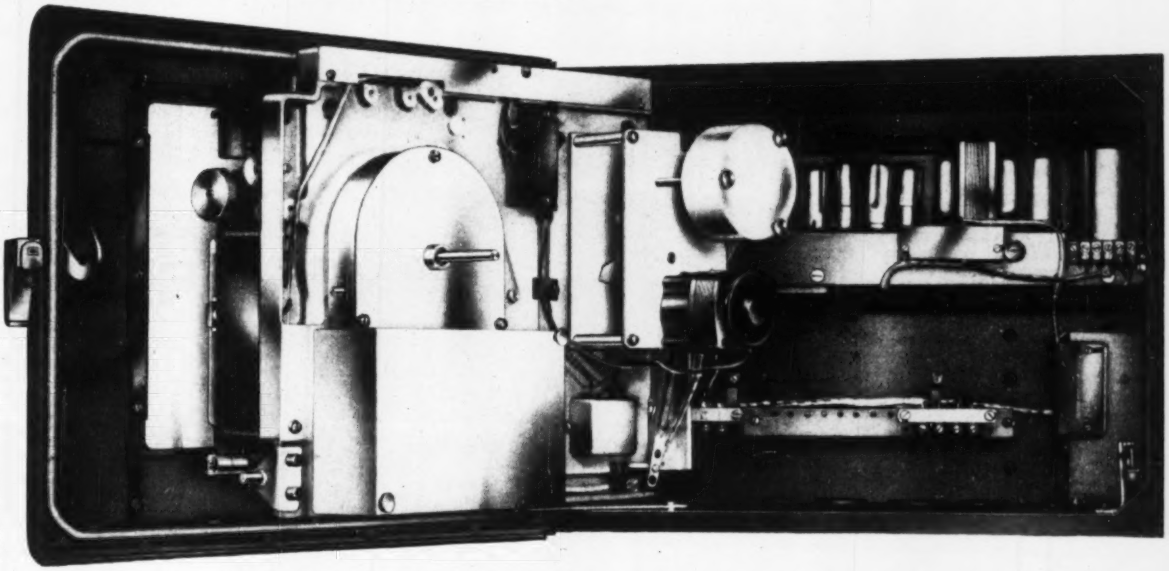
For more information circle **243** on inquiry card.

DISPLACEMENT

Displacement Pickups

New "Lyn-A-Syns" are available in 32 models with ranges from 0.003 in. to 2 in.; utilize mutual-inductance principle: displacement of high-permeability core (in either direction from center null) causes a linear increase in output voltage. Units are

WHAT'S NEW AT BRISTOL...



CONTINUOUS STANDARDIZATION UNIT of the electronic Dynamaster eliminates need for dry cells and standardizing mechanism. Result: no interruptions in operation for standardization; no batteries to replace.

Measures any variable that can be translated into an electrical quantity

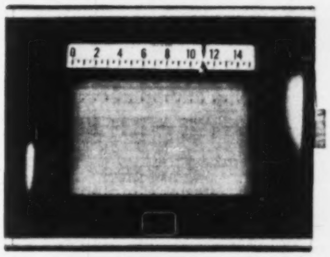
Bristol's Dynamaster Potentiometers have earned a world-wide reputation for accuracy and dependability in recording, indicating, and controlling temperature, pH, speed, voltage, power, current, resistance, smoke density, strain — the list could go on and on.

Behind this reputation is 65 years of instrument-making research and experience — all aimed at making Bristol instruments as precise and trouble-free as humanly possible.

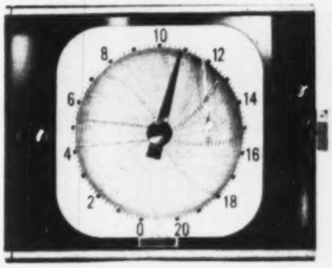
One result of this research is our new No-Batt continuous standardization system, which is used in Dynamaster Potentiometers and Pyrometers. With continuous standardization eliminating the need for dry cells, the potentiometer is free to continuously measure, record and control. No time out is required for periodic standardization.

And all Dynamasters are "human-engineered", making them easier to read and clearly visible at greater distances. Simplified construction, fast operation, fewer moving parts are all achieved through Bristol's "human engineering".

Get the whole story on these rugged, precision instruments. Write today for free 36-page bulletin P1245. The Bristol Company, 113 Bristol Road, Waterbury 20, Conn. 4.26



BRISTOL ELECTRONIC DYNAMASTERS are made in round- and strip-chart, single- and multiple-record recorders, air-operated and electric controllers (all types of control actions). Two-pen and Program Control.



BRISTOL

POINTS THE WAY IN HUMAN-ENGINEERED INSTRUMENTATION

AUTOMATIC CONTROLLING, RECORDING AND TELEMETERING INSTRUMENTS

For more information circle **39** on inquiry card.

inductively and resistively balanced for minimum null signals; may be obtained magnetically shielded or wound for high-temperature operation.—*Minatron Corp., 3 Cliveden Pl., Belle Mead, N. J.*

For more information circle **244** on inquiry card.

Motion-pickup Amplifier

New "Model 400" is for use with mutual-inductance type displacement transmitters; enables measuring static, transient, or oscillatory force, pressure, strain, acceleration, etc. Unit includes a carrier oscillator, demodulator, and all circuits necessary to provide suitable input to CRO. Flat frequency response from 0 to 1000 cps. within ½ db.; core displacements as small as 0.0001 in. can be accurately measured.—*Daytronic Corp., 216 S. Main St., Dayton 2, Ohio.*

For more information circle **245** on inquiry card.

COMPUTING, ETC.

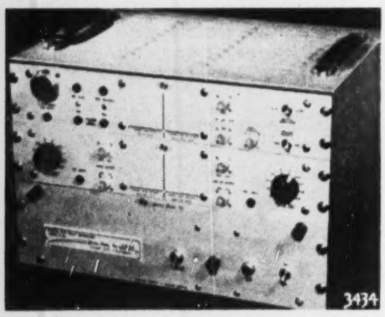
Computer

New "Model CRC 102-A Electronic Computer" and its auxiliary "Magnetic Tape Unit Model CRC 126" are designed for: (1) data processing, (2) problem solving and (3) record keeping in both scientific and business areas. Among claimed advantages of new system are: Compact size, since entire system can fit in an ordinary business office; no special air conditioning; cost a fraction of investment in so-called "giant brains"; versatility with ability to accept input from any of the numerous new business and scientific machines which have punched paper tape output.—*Electronics Div., The National Cash Register Co., 3348 W. El Segundo Blvd., Hawthorne, Calif.*

For more information circle **246** on inquiry card.

Time Delay Generator

New "Model 2510A Digital Time Delay Generator" produces digital increments of 10 usec. based on a 100-kc. quartz crystal. Crystal oscillator is started by input trigger; continues until pre-set delay occurs. Final delayed pulse is then used to re-set preset counters and control circuitry, readying it for next trigger pulse. Analog fill-in from 2 to 12 usec. enables one to obtain any delay from 2 to 1,002 usec.—*Electro-Pulse, Inc., 11811 Major St., Culver City, Calif.*



For more information circle **247** on inquiry card.

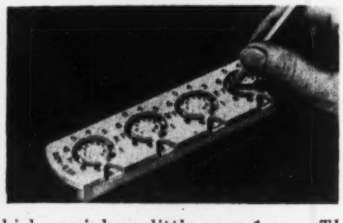
Data-handling Systems

New high-speed automatic system, including conventional office machines, makes it possible to perform clerical tasks automatically at electronic speeds; can process any kind of data, from inventory records to petroleum prospectors' test shots, in a matter of thousandths of a second for a single datum. Printed results and graphs are available. Low cost: a fraction of investment in so-called "giant brains."—*Electronics Div., National Cash Register Co., 3348 W. El Segundo Blvd., Hawthorne, Calif.*

For more information circle **248** on inquiry card.

Pocket Adder

New "Kes-Add" adds, multiplies and divides; is 5 in. long and 0.5 in. thick; weighs a little over 1 oz.—*The Hart Vance Co., St. Louis 3, Mo.*



For more information circle **249** on inquiry card.

Tape-chart Recorder

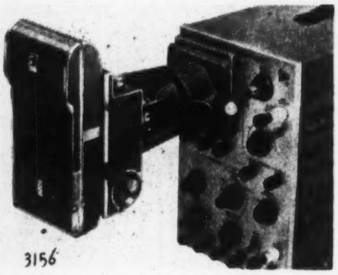
New "Model 54-A Multiple-traverse Graphical-numerical Recorder" uses standard cash register tape but achieves large-scale record without loss in accuracy through multiple traverses of tape. Line graph is supplemented by numerical printing of traverse identification. Chart drive can be clock time or a variable (numerically printed on tape). Multiple-channel units can be furnished in stacked form; basic unit furnished for mechanical shaft input to fit user's own servo follow-up system. Available unit package consists of one or more channels complete with servo amplifiers, controlled transformers or pots, motors and gear trains to meet user's requirements.—*L. & O. Research & Development Corp., 134 N. Wayne Ave., Wayne, Pa.*

For more information circle **250** on inquiry card.

PHOTOGRAPHY

Oscilloscope Camera

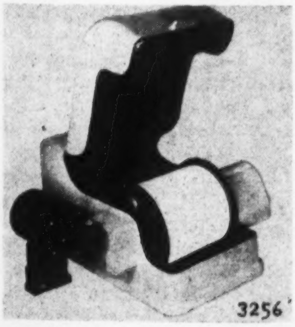
New "Recordoscope 1185" is a fully automatic oscilloscope camera adaptation of "Polaroid" fast-print principle: delivers finished black field print in 60 seconds or less. Fully-automatic magazine-shifting mechanism records 3 to 16 traces per 3 x 4-in. print.—*Aremac Associates, 329 W. Washington St., Pasadena 3, Calif.*



For more information circle **251** on inquiry card.

Rotating-drum Cameras

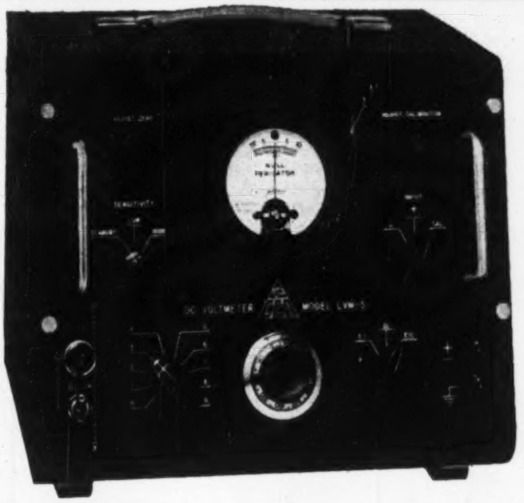
New drum cameras have 6-in. and 12-in. diameter drums; film speed of 2400 ips. is available in "Model 912." Instrument may be used for multichannel recording of cathode-ray oscillographs, also movement of a light spot reflected from mirror on string galvanometer or Bourdon tube, also movement of objects in motion.—*Allegany Instrument Co., Inc., 1000 Oldtown Rd, Cumberland, Md.*



For more information circle **252** on inquiry card.

Recording Camera

New "Beattie Varitron-S" for 35-mm. film is a unitized compact model of 70-mm. "Varitron" all-electric recording camera. It differs from earlier models in that it is a complete unit; film magazine is not detachable from main body. It is focused by lens scale and bore sight; is furnished with ground glass and angle mirror unit; may be ordered with a non-focusing



HIGH RESOLUTION LABORATORY STANDARD DC VOLTMETERS

For most applications these rugged portable, self-contained nulling voltmeters replace a potentiometer, voltbox, galvanometer and standard cell combination. They are suitable for laboratory use, production line testing and field service.

Model LVM-5

Voltage Range:	0-100 Volts DC
Resolution: At least	50 microvolts between 0 and 1 volt
	500 microvolts between 1 and 10 volts
	5 millivolts between 10 and 100 volts
Absolute Accuracy:	± 0.1% of reading
Input Impedance:	Infinite at null

Model PVM-4

Voltage Range:	0-600 Volts DC
Resolution: At least	5 millivolts between 0 and 10 volts
	50 millivolts between 10 and 600 volts
Absolute Accuracy:	± 0.1% of reading
Input Impedance:	Infinite at null

The Model LVM-5 may also be used as a deflection potentiometer, a sensitive null indicator and a precision millimicroammeter. Write for catalog PL which describes these instruments completely. Address Dept. IA 12.

Computer Company of America, Division of Bruno-New York Industries Corp. also manufactures the IDA analog computers and accessories. Their usefulness in the field of dynamics has been proven over the years.

A complete line of standard computers, instruments and regulated power supplies is supplemented by the ability to design and manufacture specialized equipment for your particular applications. Your inquiries are invited.

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For more information circle **40** on inquiry card.

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STRAIN GAGE BALANCE FOR AIRCRAFT WEIGHING
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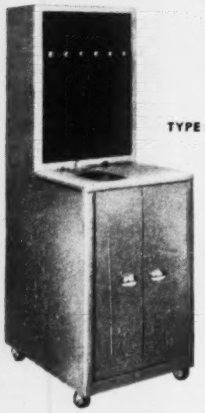
For more information circle **41** on inquiry card.

DYNOGRAPH RECORDINGS

Here is exceptional stability, sensitivity and versatility that allows simultaneous direct recordings of a wide variety of transient variables.



OFFNER DYNOGRAPH RECORDER

A high speed, direct writing oscillograph with chopper type amplifier.

30 times as sensitive. The Dynograph has a d-c sensitivity of over 15 microvolts per millimeter.

Absolutely non-drifting. While competitive recorders drift 1 mv per hour or more the Dynograph is absolutely non-drifting.

Over 8 cm of pen excursion. This high amplitude of response permits the recording of large dynamic variations.

One amplifier for all uses. Other recorders require three or more separate amplifiers for the same applications.

For technical details write for Bulletin L-742.

OFFNER ELECTRONICS INC.
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For more information circle **42** on inquiry card.

3363

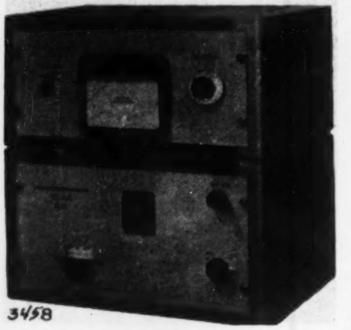
lens pre-focused for any distance. Lenses are standard 35-mm. f2.5 Angenieux in focusing mount.—*Photographic Products, Inc.,* 1000 *North Olive St., Anaheim, Calif.*

For more information circle **253** on inquiry card.

LABORATORY

Microspectrophotometer

New double-beam microspectrophotometer can be used to analyze solutions in volumes from several milliliters down to 0.015 ml.; design allows use of interchangeable micro and macro cuvettes without change of components or settings. Readings (of ratio of optical densities of concentrations) are linear with concentration; system reduces lapsed time per sample to approx. 30 sec. and makes possible time reaction studies. Ultraviolet and visible light sources are instantly interchangeable.—*Jarrell-Ash Co.,* 26 *Farwell St., Newtonville, Mass.*



3458

For more information circle **254** on inquiry card.

Spectrophotometer

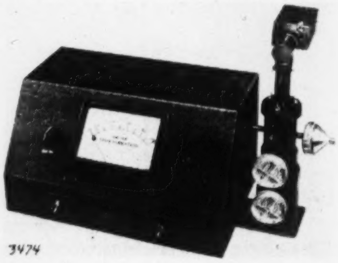
New "Model 14 Cary Recording Spectrophotometer," with wavelength range extended to include near infrared and with increased photometric accuracy, incorporates a newly designed double monochromator and flicker beam photometric system. It automatically records absorption spectra in wavelength region of 2000 A to 2.6 microns. Accuracy 0.002 absorbance units or 0.2 percent of absorbance being read, whichever is greater. Dual pen recorder's absorbance range of 0.0 to 2.0 is made to cover an effective chart width of 20 in. Standard attachments and individual special instrument modifications may be obtained. —*Applied Physics Corp., Pasadena, Calif.*

3507

For more information circle **255** on inquiry card.

Aerosol and Smoke Photometer

New "JM-1000" forward-scattering aerosol and smoke photometer features extreme sensitivity by measuring forward-scattering at small angles which may be 100 to 10,000 times greater than scattering in all other directions. Many standard and special accessories are available such as recorders, logarithmic and linear amplifiers.—*Phoenix Precision Instrument Co.,* 3803-05 *N. 5th St., Philadelphia 40, Pa.*

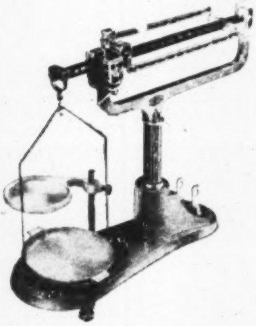


3474

For more information circle **256** on inquiry card.

Triple-beam Balance

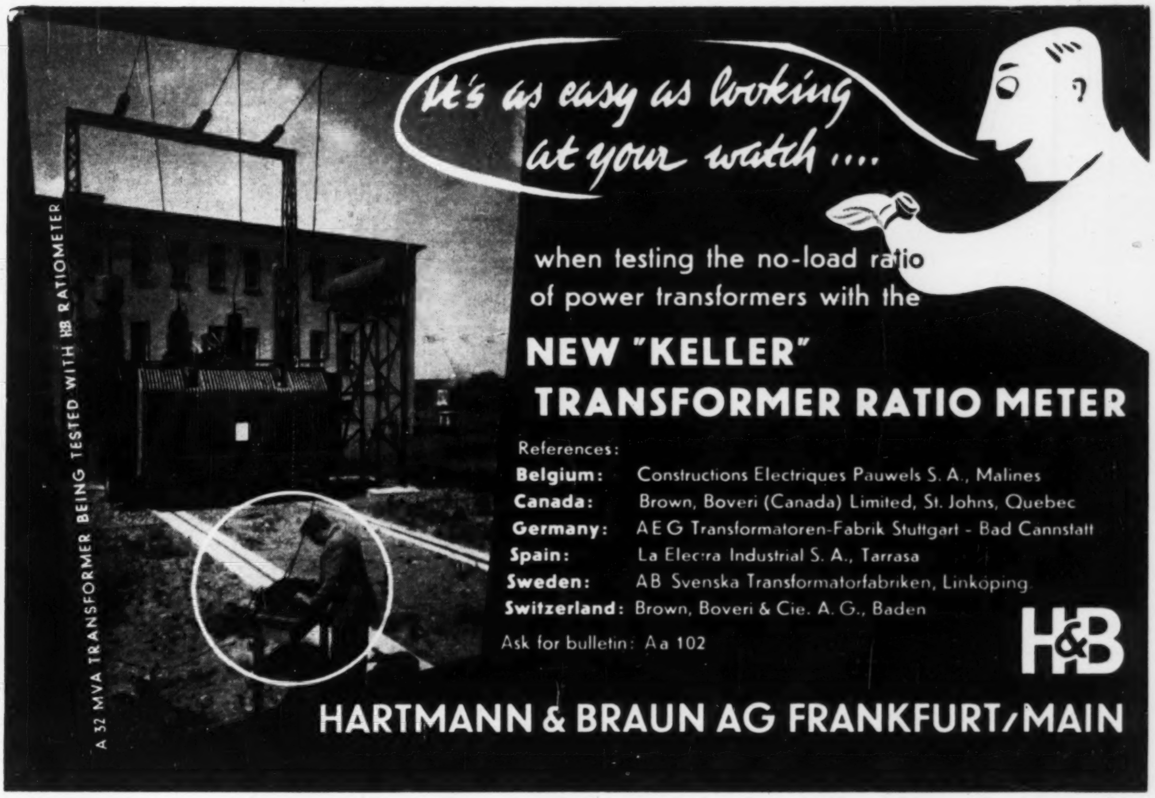
New "Cent-O-Gram Model C.G. 311," with sensitivity of 0.01 gram and capacity of 311 grams, bridges gap between analytical balance and conventional trip balance. Exposed parts are stainless steel.—*Ohaus Scale Corp.,* 1050 *Commerce Ave., Union, N. J.*



For more information circle **257** on inquiry card.

Blood-count Automator

New "Arithmometer" makes complete blood counts automatically in less than 2 minutes. A built-in microscope forms an image of the cells in front of a photomultiplier, which detects the image of each cell that passes across its photocathode; resulting


A 32 MVA TRANSFORMER BEING TESTED WITH H&B RATIOMETER
It's as easy as looking at your watch....

when testing the no-load ratio of power transformers with the

NEW "KELLER" TRANSFORMER RATIO METER

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Belgium:	Constructions Electriques Pauwels S. A., Malines
Canada:	Brown, Boveri (Canada) Limited, St. Johns, Quebec
Germany:	AEG Transformatoren-Fabrik Stuttgart - Bad Cannstatt
Spain:	La Electra Industrial S. A., Tarrasa
Sweden:	AB Svenska Transformatorfabriken, Linkoping
Switzerland:	Brown, Boveri & Cie. A. G., Baden

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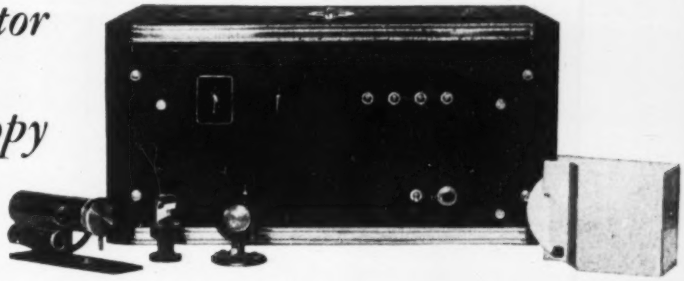
For more information circle **43** on inquiry card.

A Superior Detector
for
Infra-Red Spectroscopy

GOLAY PNEUMATIC DETECTOR



Among the characteristics that render the Golay Detector superior to other types of detectors for use in infrared spectroscopy are:

1. An effective sensitive area 3/32" in diameter.
2. Sensitivity of 6×10^{-11} watts RMSENI when used with "chopped beam" method and with recording time constant of 1.6 second.
3. Uniform sensitivity from the ultra-violet through the visible and the entire infra-red, and up to the micro-wave region.
4. Improved, drift-free, A.C. operated amplifier with step gain controls and four response periods.

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For more information circle **44** on inquiry card.

FOR RAPID AMBIENT TEMPERATURE TESTS

PORTABLE TEMPERATURE TEST CHAMBER

MODEL TC-2

PRICE $550.00
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The Model TC-2 Temperature Test Chamber is a portable, self-contained, easy-to-operate unit ideal for laboratory and production line use.
Write for literature.

Temperature Range: —65°F to +350°F.
Holding Accuracy: ±2°F.
Coolant: Dry ice, 15 lbs. capacity. Dry Ice Loading Port.
Heater: Electric Strip Heater.
Control: Thermostat, balancing heat against dry ice evaporation. Permanent Thermometer.
Test Load Access: Removable tray, with 15 through ports.
Test Load Capacity: 600 cubic inches.
Power Requirements: 115 volts, 5 amperes, 50-60 cycles, single phase.

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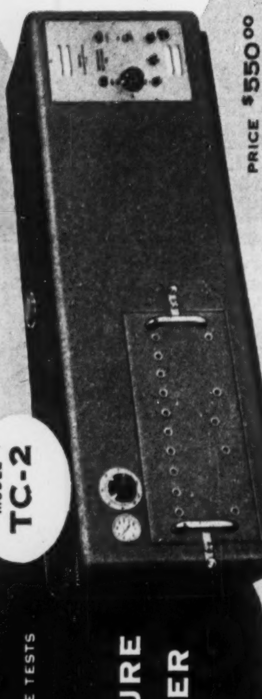
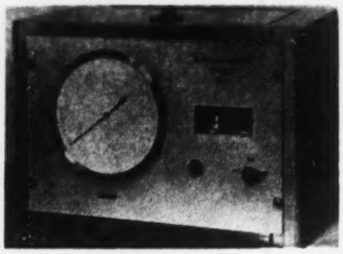


For more information circle 45 on inquiry card.

NEW INSTRUMENTS

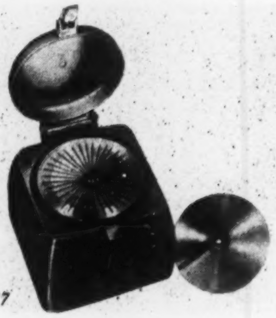


pulses are fed into a simple computer circuit; count is displayed on a dial calibrated in millions of red cells per cubic mm. and in tens of thousands of white cells per cubic mm. Blood may be analyzed for white or red cells by panel switch selection and choice of solution in which cells are suspended.—*Jarrell-Ash Co., 26 Farwell St., Newtonville, Mass.*

For more information circle **258** on inquiry card.

Centrifuge

New "Series 54 Electrifuge-Hematocrit" is designed to conduct 36 tests simultaneously; utilizes new improved Guest-Siler technique with heparinized capillary tube.—*Chicago Surgical and Electrical Co., 217 N. Desplaines St., Chicago 6, Ill.*



For more information circle **259** on inquiry card.

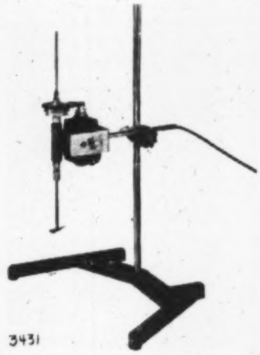
Dry-atmosphere Box

New portable (15-lb.) transparent-plastic "Controlled Atmosphere Dry Box" features sealproof hand entry diaphragms; can be hermetically sealed in 30 seconds. Relative humidity is automatically controlled to a constant 1 percent. Standard air-lock, filter system to control dust to 1 micron, glove assembly, etc. Because of low price, fast delivery, box can be thrown away after radioactive contamination.—*P. M. Lennard Co., Inc., 671 Bergen St., Brooklyn 38, N. Y.*

For more information circle **260** on inquiry card.

Laboratory Stirrer

New "3-Speed Stirrer" features maker's "Hollow Spindle" and continuous light duty operation at 500, 750 or 1000 r.p.m.; 1/50-hp. split-phase induction motor by Bodine develops 4 oz.-in. torque.—*Eberbach Corporation, Ann Arbor, Mich.*



For more information circle **261** on inquiry card.

Zirconium-arc Outfit

New Zirconium Arc Lamp Illuminator and Power Supplies combine to form a complete self-contained system. Superiorities of new lamp are said to include: Source as small as 0.003 in.; intensity up to 46,000 ft.-c./sq. in.; low heat content of light beam; favorable spectral distribution; availability in sizes 2, 10, 25, 100 and 300 watts.—*Burton Mfg. Co., 11201 W. Pico Blvd., Los Angeles 64, Calif.*

For more information circle **262** on inquiry card.

DIMENSIONAL

Measuring Microscope

New direct-measuring erect-image microscope on industrial-type base allows much greater flexibility in use than maker's unmounted pocket comparator.—*Edmund Scientific Corp., Barrington, N. J.*

For more information circle **263** on inquiry card.

I. D. Gage

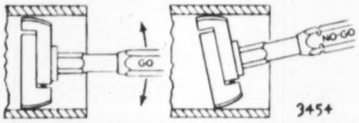
New "Tube Gage" measures inside diameters of small tubes and tube sheet openings in condensers and heat exchangers; reads directly in thousandths; enables tube expanders and controls to be set accurately for exact tube rolling; utilizes three-point contact method essential for accurate tube measure.—*Lagonda Division, Elliott Co., Springfield, Ohio.*

For more information circle **264** on inquiry card.

I. D. Gages

New "Adjustable Boregages" are said to "provide the first major advance in simplification and cost reduction of bore gaging since the development of the plug gage." Fifteen sizes, 0.995 in. to 6.005 in. Photo and drawings show features and method of use.—*M. C. Hutto Co., 6516 Detroit Ave., Cleveland 2, Ohio.*

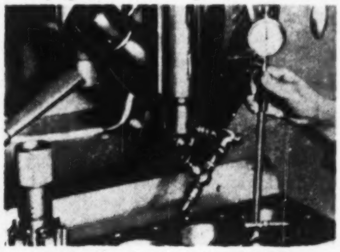
GREEN
RED
3454



For more information circle **265** on inquiry card.

I. D. Gage

New "Self-Centering Dial Small Bore Gage" checks bores rapidly for size, taper, oval form and bell-mouth at any point and depth; is centered automatically inside bore by means of a spring-loaded bridge whose cradle-shaped ends form an equilateral triangle with feeler point. Measurements are taken by inserting shaft into bore, rocking it around and reading dial. Seven standard sets, in ranges from 0.2 in. to 4 in.—*George Scherr Co., Inc., 200 Lafayette Street, New York 12, New York.*



For more information circle **266** on inquiry card.

I. D. Gage Kit

New "Adjustable Airebore Gage Kit" permits any size hole between 3 and 12 in. diam. to be inspected for size, taper, and out-of-roundness.

for fast response
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USE New DIEHL

INSTRUMENT SERVO MOTORS

Designed for use on recording instruments where rapid acceleration and deceleration are of primary importance.

DIEHL Instrument Servo Motors feature a novel construction with an integrally molded stator and housing. Liberal design characteristics are built-in so that long life can be expected even under severe ambient temperature conditions.

While intended primarily for commercial use, these Servo motors meet pertinent JAN specifications for resistance to humidity, salt spray, fungus, shock and vibration.

SPECIFICATIONS	DIEHL NUMBER	
	FPE21L-27-1	FPE25L-92-1
Output (Watts)	1	5
Frequency (Cycles)	60	60
Poles	2	2
Reference Phase (Volts)	115	115
Control Phase (Volts)	50	115
Reference Phase (Watts)	10	17
Control Phase (Watts)	3.5	17
Control Phase Impedance (Ohms)	555	575
Locked Torque (Oz.-In.)	1.5	5.5
Theoretical Acceleration (Rad/sec.^{2})	9650	19000

Our engineering staff will gladly help you select the motors best suited to your specific requirements. A request on your letterhead will bring you a copy of Technical Manual No. IN-1254 describing Diehl Servo Motors and related equipment.

Other Available Components:
D.C. SERVO SETS • RESOLVERS
MINIATURE PERMANENT MAGNET D.C. MOTORS

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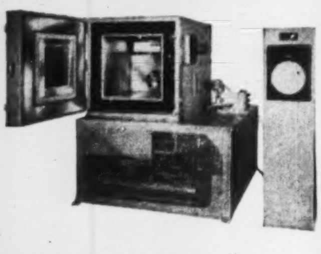
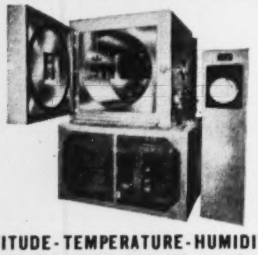
Finderne Plant, SOMERVILLE, N. J.

For more information circle **46** on inquiry card.

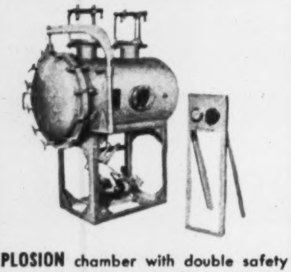
AR★
ENVIRONMENTAL
TEST EQUIPMENT



TEMPERATURE-HUMIDITY test chamber with automatic control of temperature from +500° F to −100° F and lower.



ALTITUDE-TEMPERATURE-HUMIDITY cylindrical test chamber with completely automatic operation and recording; +500° F to −100° F, to 80,000 ft. and higher.



EXPLOSION chamber with double safety features for testing under explosive atmosphere conditions up to 50,000 ft.

American Research offers a complete line of Environmental Test Equipment for simulating conditions of high and low temperature, altitude, relative humidity, sand and dust, rain and sunshine, fungus, explosion, gas and air chilling, etc. • Designed and built in a variety of sizes and ranges to meet all government specifications and individual requirements.

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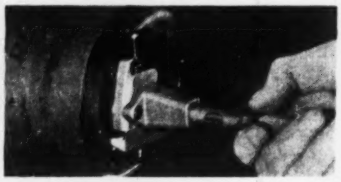
For more information circle **47** on inquiry card.

NEW INSTRUMENTS



It consists of a triangularly shaped spindle body to which are mounted a "Plunjet" gaging cartridge, and these interchangeable components: centering foot, handle connector, length extensions, and adjustment screw. "Plunjet" cartridge, connected to a column type "Precisionaire," provides 1000 to 1 amplification.—*Sheffield Corp., Dayton* 1, *Ohio.*

For more information circle **267** on inquiry card.

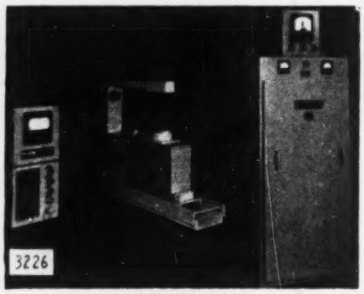
MACHINE AUTOMATION

Gear-line Automation

New modification of maker's "3-way Gear Selector" is applicable to practically any gear cutting or finishing machine, permits automatic controlling of such machines: automatically re-adjusting each machine any time an oversize or undersize gear comes off that machine. Device will correct machines for dimensional errors caused by tool wear and even by changes in temperature during the day. It operates by automatically comparing each gear produced against two master gears.—*Michigan Tool Co.,* 7171 *E. McNichols Rd., Detroit, Mich.*

For more information circle **268** on inquiry card.

Rolling-mill Controller



New automatic system for controlling thickness of metallic strip leaving cold reduction mills operates in conjunction with maker's "Measuray," and "X-ray Thickness Gage," raises or lowers screwdowns on mill. System is said to include "controls that anticipate whether screwdowns need adjusting either up or down. This feature eliminates hunting and/or overcorrection, thereby holding closer tolerances than ever before." —*Sheffield Corp., Dayton* 1, *Ohio.*

For more information circle **269** on inquiry card.

Rolling-mill Controller

New "Model E Automatic Mill Gage Control Unit," for use in conjunction with continuous mill gages, automatically corrects thickness variations in materials being rolled. Whenever gage registers an undersize or an oversize, unit commands screwdown motor (or other mechanism) intermittently, allowing a delay for correction to reach gage. Duration of correction is proportional to deviation, to prevent hunting and overshooting. Safety features: automatic shut-down of unit for: tube failure, mill stoppage or slow-down below preset rpm., or correction process taking too long. —*Pratt & Whitney, Div. Niles-Bement-Pond Co., West Hartford* 1, *Conn.*

PRATT & WHITNEY
3366

For more information circle **270** on inquiry card.

Tool-operation-count Preset Controller

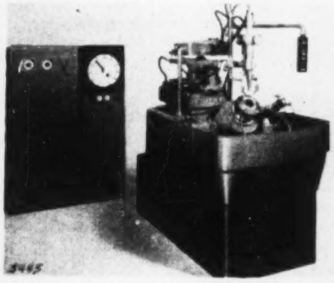
New "Tool Control Unit," for screw machines, drill presses, gear hobbers, punch presses, etc., is available in four sizes with one, two, four or eight "Toolometers." Pointer on each "Toolometer" is set at a count representing expected output of pieces per tool sharpening, at which point machine automatically shuts down for tool change.—*The Cross Co., Dept. 59P, Detroit* 7, *Mich.*

CROSS
TOOL CONTROL UNIT
3424

For more information circle **271** on inquiry card.

Automatic Gear Hardener

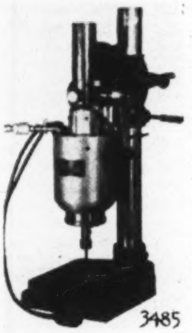
New "No. 1 Gear Surface Hardener" features automatic control as oxy-acetylene flames traverse each individual tooth separately: radiation pyrometer, focused on tooth being heated, commands a balancing mechanism which controls travel of burners along tooth. Operation is entirely automatic after temperature is set and machine started. In normal oper-



ation, machines are indexed so that teeth hardened successively are nonadjacent. This prevents change in bore diameter during hardening; minimizes internal stresses. Water or oil quenching if desired, and adjustments for coolant streams as close to or as far from heating point as desired.—*The Gleason Works, 1000 University Ave., Rochester 3, N. Y.*

For more information circle **272** on inquiry card.

Automatic Tapper



3485

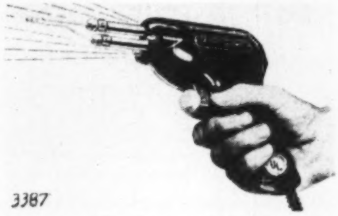
New automatic electropneumatic tapping unit, for high-speed sensitive threading (to 5/16 in.) with complete elimination of tap breakage, incorporates an air motor with electropneumatic control which provides for momentary tap reversals at rates up to 200 cycles per minute. Tap chuck is driven by a mechanism supersensitive in detecting resistance to cutting force. Hole depth can be preset to 0.0035 in. Unit operates from plant air supply (70-125 psi.). Time for operation cycle—exclusive of tapping time—is less than a half-second.—*Smith & Wiese Co., 1265 W. 2nd St., Cleveland 13, Ohio.*

For more information circle **273** on inquiry card.

SHOP EQUIPMENT

Soldering Gun

New "Junior Model 8100" soldering gun with ample power for all general soldering (over 100 watts) incorporates many features found in larger models; makes a useful second soldering gun in tool kit; will withstand impact of other tools.—*Weller Electric Corp., 808 Packer St., Easton, Pa.*



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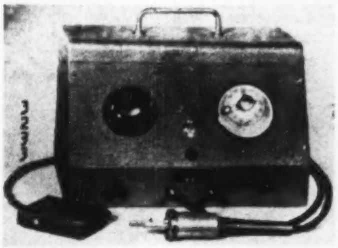
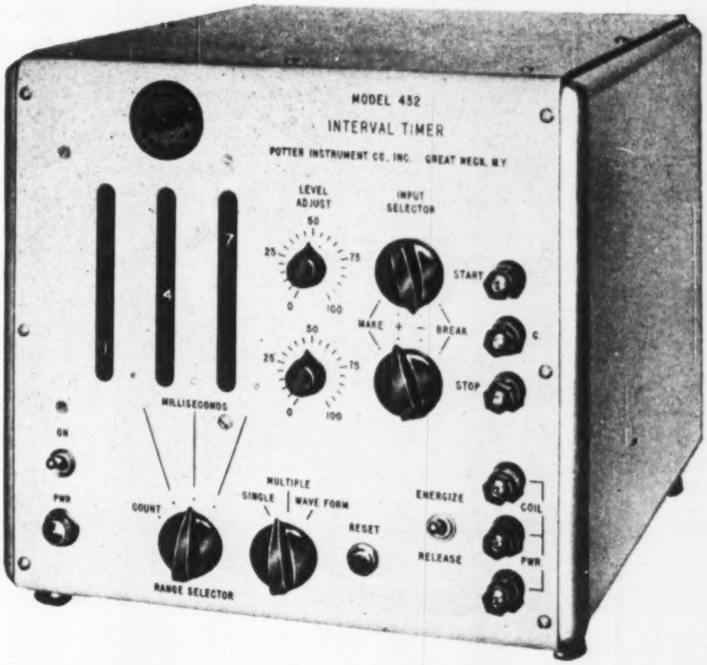
For more information circle **274** on inquiry card.

Soldering Unit

New "Model 23" was developed for soldering printed circuits, germanium diodes, transistors, etc. Method pre-





Here's a low-cost solution to your high-precision timing problems

The New Potter Model 432 Interval Timer is a general-purpose instrument for timing relays, camera shutters, high-speed machine operations, and for calibrating electrical and mechanical timing devices. It is simple to operate—even an unskilled operator can make interval measurements to within 0.00001 second.

Versatile Input Circuits permit measurement of time between any combination of voltage changes, contact opening, or contact closure, thus accommodating a wide variety of timing problems.

Timing Is Achieved by Electronically Counting the number of pulses produced by a high-frequency crystal-controlled time-base oscillator during the unknown interval. Three time-base frequencies (1, 10, and 100 kc) are provided for making measurements in increments of 0.01, 0.1, and 1 millisecond. Results are displayed directly in milliseconds with an illuminated decimal point—misinterpretation of readings is virtually impossible.

Maximum Timing Range of the 432 is 1 second; this can be extended to 1,000,000 seconds by addition of a mechanical register (available as an optional feature). The 432 also serves as a totalizing counter (can be used to count relay contact bounces) and as a secondary frequency standard with outputs of 100 kc, 10 kc, 1 kc, 100 cps, 10 cps, and 1 cps for general laboratory use.

Descriptive Literature Is Yours for the asking. Write today and see how this compact, low-cost instrument can solve your timing problems with greater accuracy and convenience.

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115 Cutter Mill Road, Great Neck, N. Y.

For more information circle **48** on inquiry card.

below 800° F.

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XACTEMP

Low Temperature · General Purpose HAND PYROMETER

Type LT-840 Low temperature Xactemp Pyrometer with rigid extension arm and surface tip thermocouple.

1001 USES

This is the answer to quick, accurate temperature readings below 800° F. in many industrial processes and operations. And it's so convenient to handle.

The Xactemp hand-type pyrometer, Model LT-840, is used with needle thermocouples, ribbon thermocouple, surface tip thermocouple, and other specially designed thermocouples and extension arms. These are easily interchangeable and, without adjustments or recalibration of the instrument, quickly ready it for measuring the surface temperature of stationary and revolving rolls and cylinders, flat and irregular surfaces of molds, dies, etc. in rubber and paper making, plastic materials, rubber, wax, oils, greases, and other semifluid materials.

Handy, compact design makes this Xactemp pyrometer ideal for field service, laboratory, and production-line use.

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For more information circle 49 on inquiry card.

vents overheating or burning of parts. Soldering can be controlled closely by means of adjustable heat-controller, and timer.—*Vemaline Products Co., P. O. Box 222, Hawthorne, N. J.*

For more information circle **275** on inquiry card.

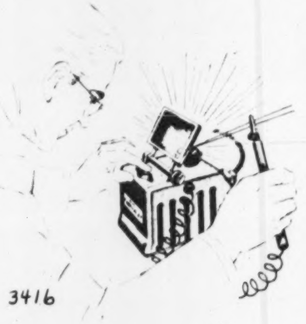
Steel Soldering Flux

New "Poly-Flux" is a liquid flux formulated to make solder flow and hold on iron and steel as easily as on copper, bronze, zinc, etc.; thoroughly removes surface oxides; comes in 2-oz. containers.—*Industrial Craftsmen, Inc.,* 145 *High St., Boston* 10, *Mass.*

For more information circle **276** on inquiry card.

Thermocouple Welder

New "Kup-L-Weld" provides welding by push button, available for instantaneous use. Many different metals and alloys, in wire sizes from 14 to 30, can be joined.—*Burrell Corp.,* 2223 *Fifth Avenue, Pittsburgh* 19, *Penna.*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For more information circle **277** on inquiry card.

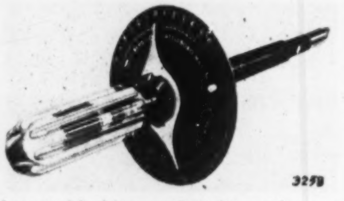
Vacuum Coater

New vacuum coater features built-in photometer which measures coating thickness; space for placing any type of filter in optical path. Vacuum system features a rapid pump-down cycling time by means of diffusion-pump by-pass valves. Standard items also include complete gaging, filament-heating controls and instruments, and high-voltage electrical clean-up power supply.—*American Instrument Co., Inc., Silver Spring, Md.*

For more information circle **278** on inquiry card.

Bidirectional Torque Tool

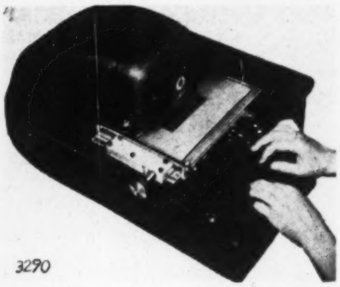
New torque tool measures both left and right torque (previous models measured right only); has interchangeable bits so that it can be used as a torque screw driver or socket wrench. Several ranges in both inch-grams and inch-ounces.—*Apco Mossberg Co., Attleboro, Mass.*


3298

For more information circle **279** on inquiry card.

Metal-marking Typewriter

New version of "Automark" electric typewriter for marking metal name plates has standard keyboard, has no levers to pull or dials to spin, can produce as many as 75 characters per minute.—*Defiance Machine & Tool Co., Inc.,* 1920 *S. Vandeventer, St. Louis* 10, *Mo.*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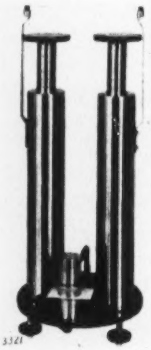
For more information circle **280** on inquiry card.

MECHANICAL TESTING

Paper Smoothness Tester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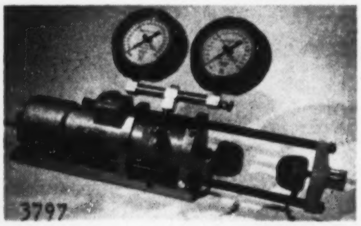
New "RD Smoothness Tester" determines smoothness of both felt and wire sides of paper, separately and simultaneously; embodies refined methods of testing paper smoothness; is for use in laboratory tests by skilled personnel, rather than in actual production (where maker's "S-P-S" [Smoothness-Porosity-Softness] tester is in use).—*Industrial Div., W. & L. E. Gurley, Troy, N. Y.*

For more information circle **281** on inquiry card.

Testing Machine

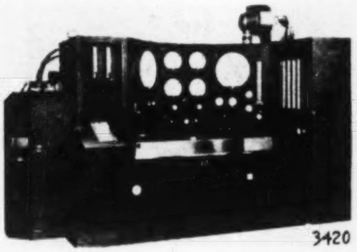
New "Model TH-5 Cal-Tester" is said to be "the first low-cost hydraulic tensile testing machine to meet the Army, Navy, Federal and ASTM specifications for a guaranteed accuracy of ±1% of indicated load," has dual capacity load ranges of 0-1000 lbs. and 0-5000 lbs.; weighs 70 lbs.; is approx. 36 in. long. Available accessories adapt machine to compression and flexure tests. Among features: self-aligning grips, replaceable insert jaws, micrometer action on loading mechanisms; automatic protection against damages from overtravel and overloading.—*Pacific Scientific Co.,* 1430 *Grande Vista Ave., Los Angeles* 23, *Calif.*


3797

For more information circle **282** on inquiry card.

Nozzle Test Stand

New "Type 416 Universal Fuel Nozzle Test Stand" contains its own supply tank, pumps, filters and temperature control system; can be supplied with both a high-pressure flowmeter and a direct-weigh system, or with flowmeter alone. Direct weigh method: time required for a known weight of fuel to flow through nozzle being tested, from where it is sprayed into cone-shaped "patternator" (at left).—*Commercial Research Laboratories, Inc., 20 Bartlett St., Detroit 3, Mich.*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For more information circle **283** on inquiry card.

Balancing Machines

New horizontal static-dynamic balancing machines feature "Electodyne" indicating system whereby automatic indication of unbalance is secured instantly for selected plane of correction: angle and amount of unbalance clearly shown; plane of correction charged quickly with pivot shifter assures positive plane separation.—*Tinius Olsen Testing Machine Co., 4058 Easton Rd., Willow Grove, Pa.*

For more information circle **284** on inquiry card.

ELECTRICAL TESTING

Electromechanical Equipment Testers

Three new test stands are capable of testing performance of Lear (or other makes of) electromechanical equipment under rated loads. Uni-

3335

Circle 50 on inquiry card. →

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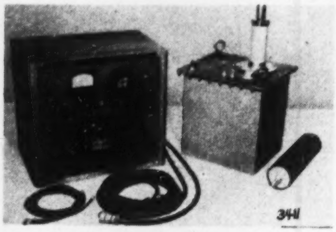
versality is achieved by means of nonspecial test leads which fit any unit, regardless of type of connection, with minimal adaptation. Test stands are available either as a package or separately.—*Field Service Dep't, Lear, Inc., 110 Ionia, N.W., Grand Rapids 2, Mich.*

For more information circle **285** on inquiry card.

Corona Test Set

New "Model 3" facilitates nondestructive testing of insulation in electrical equipment by detection of electric discharges that may result when an a-c. test voltage applied to such equipment exceeds a critical value. Sets embody safety, simplicity, and reliability to such a degree that operation by engineering personnel is not required.—*James G. Biddle Co., 1316 Arch St., Philadelphia 7, Pa.*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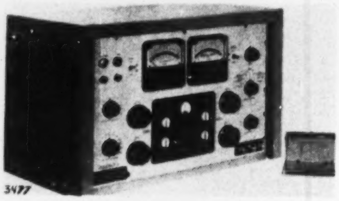
For more information circle **286** on inquiry card.

Calibration Equipment

New "Model 829 AC-DC Instrument Calibration Equipment" can be used for small-lot production testing, as a laboratory current and voltage standard, and by instrument repair groups. Electrical interlocks protect against misoperation. Calibration charts show comparison of all ranges to basic standards with recent NBS calibration certificates. Seventy-five ranges, a.c. and d.c., mv. and ma. to 1500 v.ac., 2000 v.dc., 20 amps a.c. and 20 amps. d.c.—*Radio Frequency Laboratories, Inc., Boonton 17, N. J.*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For more information circle **287** on inquiry card.

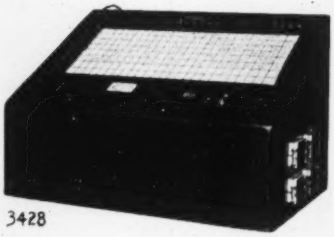
Portable Color-bar Generator

New "Model 655XC" produces a NTSC Standard, 100-perecent fully-saturated color bar pattern on picture tube of any color-TV receiver; will be compatible regardless of future color-TV receiver design. Signal is identical to signal transmitted; includes "Reference White" reference basis. Unit has provision for switching on or off Y, chroma, I, Q, R-Y or B-Y; comes in a leatherette carrying case and can be adapted for rack mounting.—*The Hickok Electrical Instrument Co., 10519 DuPont Ave., Cleveland 8, Ohio.*

For more information circle **288** on inquiry card.

Circuit Analyzer

New "Model 200 Universal Automatic Electrical Circuit Analyzer" tests complex aircraft cabling systems or control panel assemblies at speeds up to 200 circuits in 20 seconds; has 200 separate test positions with separate facilities for operating external devices such as relays, at any test position. Multiplier sections can be added, bringing standard 200-circuit analyzer (shown in photo) up to 600- or 1200-circuit capacity. Visible matrix type reference charts pinpoint circuit errors.—*Electronics Div., DIT-MCO, Inc., 505 W. 9th St., Kansas City, 5, Missouri.*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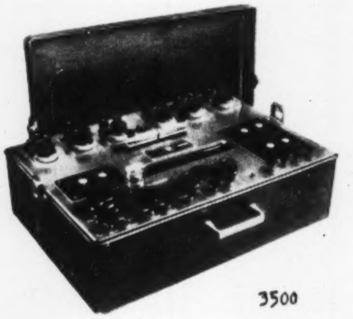
For more information circle **289** on inquiry card.

Strain-gage Bridge

New automatic strain-gage bridge is for field use by unspecialized personnel on structural members, dams, bridges, etc. It includes a setting for "*k*" coefficient of gages employed; yields direct readings of relative elongations; has six channels, each using two gages.—*A.O.I.P., 2 rue Jacqueline, Boulogne (Seine) France.*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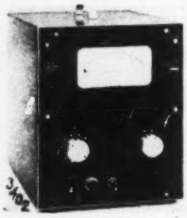
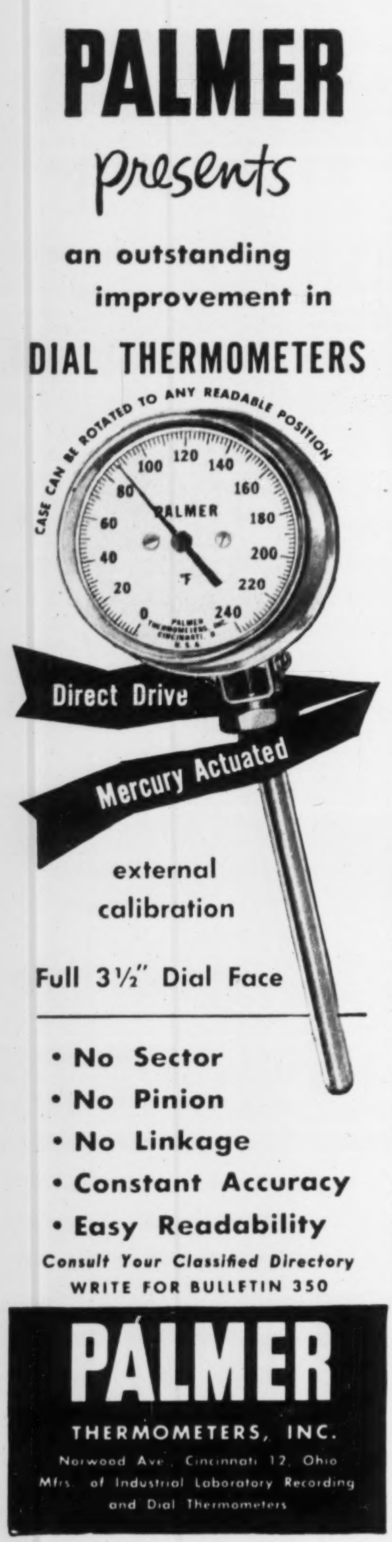
For more information circle **290** on inquiry card.

Power Supply Tester


3402

New "Model D-1 Regmeter" measures power supply internal resistances directly from 0.02 to 1,000 ohms in sources with outputs from 0 to 500 volts; may be used also as a stable a-c. voltmeter for measurements of millivolts and volts from 5 cps. to 10 kc.; serves as a general linear ohmmeter; and measures ripple and noise. Its high-gain amplifier employs negative feedback for stability and linearity.—*Alto Scientific Co., 3404 Cowper St., Palo Alto, Calif.*

For more information circle **291** on inquiry card.



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For more information circle 51 on inquiry card.

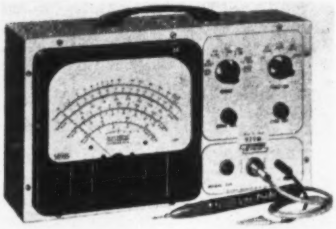
Fault Locator

New "Universal Model 54" of maker's "Brunt Faultfinder" portable ground detector and fault locator for use on energized power lines has a voltage selector switch whereby instrument may be used on power voltages of 120, 240, 480, or 550, a.c. or ungrounded d.c.—*Parr Mfg. Corp.*, 44 *Austin St., Newark* 5, *N. J.*

For more information circle **292** on inquiry card.

VTVM

New "Model 249 Peak-to-Peak VTVM" is said to offer a combination of laboratory precision and versatility features. New "Dual Purpose Ac/Dc. Uni-Probe" comes with either kit or wired instrument; is a timesaver as it performs all functions. Center scale zero adjustment for TV/-FM alignment, and for calibration from outside cabinet.—*Electronic Instrument Co., Inc.*, 84 *Withers Street, Brooklyn, N. Y.*

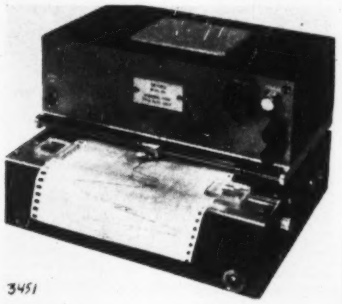


For more information circle **293** on inquiry card.

ELECTRICAL INSTRUMENTS

Rectilinear-coordinate -chart Recorder

New "Model 100" is designed to afford maximal versatility for research, product testing, etc. Input resistance of ½ megohm and full-scale sensitivity of 100 mv. permit use in



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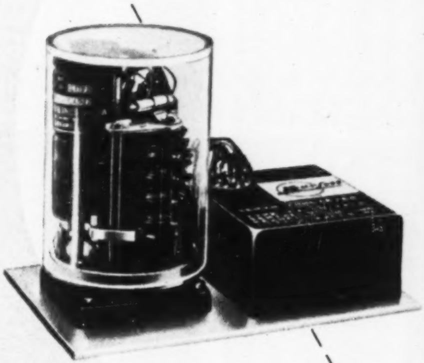

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Digital
Analog
Converter

ADAC shown in plastic case is normally **hermetically sealed** in metal cover.

ADAC is a device for the precise electro-mechanical conversion of analog information to digital form. ADAC works from a synchro voltage input and produces a 12-binary-digit informational output.

This servo driven Converter is designed to be read-out either "on the run" or "on demand". For read-out, the digital computer sends an interrogating pulse to all the drums (and their segments) in common. The pulse can only return to the computer via the brushes contacting the tracks. If a brush is on a conducting segment, the pulse returns to the computer; if the brush is on an insulated segment, the pulse is blocked. All 12 tracks are simultaneously read and the return pulses are thus coded to represent discrete steps of the transducer feeding ADAC.

By using precision servo components, the accuracy of ADAC has been reduced to one part in 4096 (.02%), or approximately 5 minutes of transmitter rotation. It weighs only 2½ pounds and measures three inches in diameter and four inches in length. The device is hermetically sealed and is highly shock resistant. The T3100 Servo Amplifier provides the necessary excitation for the servo elements of the Converter. A direct drive ADAC providing the segmented drums and necessary gear trains, and an inverse ADAC for digital-analog conversion is available.

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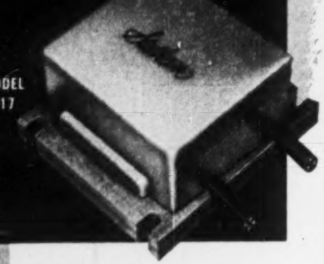
For more information circle **52** on inquiry card.

temperature
controlled
linear
accelerometers



The usefulness of Statham unbonded resistance strain gage accelerometers has been further extended by special temperature control packaging which ensures that dynamic as well as static characteristics remain constant despite temperature variations such as are encountered in flight applications.

Operation through the ambient temperature range −65° F. to +120° F. is afforded by means of an electrical heater jacket with a peak power input of approximately 20 to 30 watts.

Depicted is the Model A17 accelerometer which is offered in ranges from ±1g to ±15g. Other temperature controlled models cover ranges from ±0.5g to ±15g.

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For more information circle 53 on inquiry card.

conjunction with photocells, thermistors, etc., without additional amplification. Pen speed 1 inch per second; accuracy 1 percent; reproducibility better than 0.5 percent. Front panel zero control sets pen at any point on 6-in. strip chart. Available chart speeds from 4 ipm. to 1 iph.; extension of chart drive shaft enables mechanical synchronizing. The pen is positioned by servo of self-balancing potentiometer. Servo unit available separately for use with turntable chart drives for polar coordinate plotting or as a remote positioner.—*Hazatrol Corp., 215 Market St., San Francisco 5, Calif.*

For more information circle **294** on inquiry card.

Cathode-ray 'Scope

New "Type 327" CRO, capable of precise measurements of time and amplitude within frequency range of d.c. to 5 Mc., has convenience and precision of a laboratory quality instrument without a premium price for unneeded bandwidth. Linear vertical amplifier which can be calibrated for full-scale deflection makes it a cathode-ray voltmeter. Fifty-nine precisely calibrated steps of sweep generator cover range of 1 sec. to 1 usec. duration on a 4-in. scale.—*Instrument Division, Allen B. Du Mont Laboratories, Inc., Clifton, N. J.*

For more information circle **295** on inquiry card.

Portable Standard

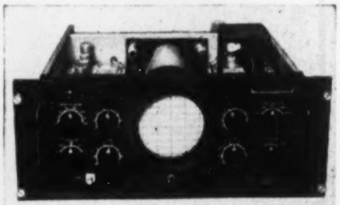
Newly redesigned "Model C Reference Standard Polyranger" features 14 ranges of current and voltage; accuracy of 0.25 percent; 6-in. scale length; exceptionally high torque-weight ratio.—*Sensitive Research Instrument Corp., 9 Elm Ave., Mt. Vernon, N. Y.*

3483

For more information circle **296** on inquiry card.

Rack-mounted 'Scope

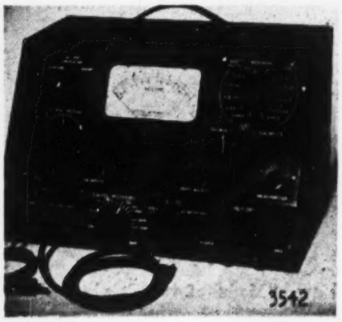
New "FT-11" single-channel oscilloscope can become an integral part of operating and control equipment. Feature is accessibility of all components despite rack mounting. Flat-face 5-in. CRT is of electrostatic focus and deflection type. Accelerating potential is 2000 v. over-all. Frequency range of both horizontal and vertical amplifiers is 0 to 100 kc. down 3 db at 200 kc.—*Electronic Tube Corp., 1200 E. Mermaid Lane, Philadelphia 18, Pa.*



For more information circle **297** on inquiry card.

Megohmmeter

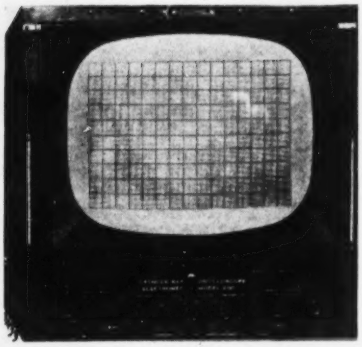
New "Megpot" can test to 10 million megohms at 200 or 500 v.dc.; is combined with a 3000-v.ac. high-potential test set and built-in calibrator. Indicator with range of 0.02-3.0 ma. flashes when allowable leakage is exceeded.—*National Instrument Co., Div., General Hermetic Sealing Corp., 99 E. Hawthorne Ave., Valley Stream, N. Y.*



For more information circle **298** on inquiry card.

Large-screen 'Scopes

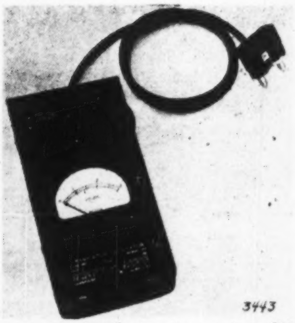
New large-screen oscilloscopes with 21-in. and 17-in. rectangular tubes are designed for data plotting, production test, waveform analysis, education, etc. Among features are 1 percent linearity, calibrated time base (from 10 usec./in. to 1 sec./in.), calibrated gain controls, low rate of drift and excellent long term stability.—*Electromec, Inc., 3200 N. San Fernando Blvd., Burbank, Calif.*



For more information circle **299** on inquiry card.

Transistor A-f. Oscillator

New "Type 1307-A Transistor Oscillator," self-contained (including batteries and output meter) is small enough to be held easily in one hand. Two frequencies, 400 and 1000 cps., are available with a maximum output of at least 2 volts across a 600-



ohm load. Output voltage is adjustable and is indicated.—*General Radio Co., Cambridge 39, Mass.*

For more information circle **300** on inquiry card.

Potentiometer and Millivolt Source

New "Model P-55" features size and weight about one-third those of other makes; has dual input (with internal switch); range 0-50 mv.; smallest reading 0.01 millivolt. Battery life guaranteed two years.—*Allegany Instrument Co.,* 1000 *Oldtown Rd., Cumberland, Md.*

For more information circle **301** on inquiry card.

ELECTRICAL-INSTRUMENT ACCESSORIES

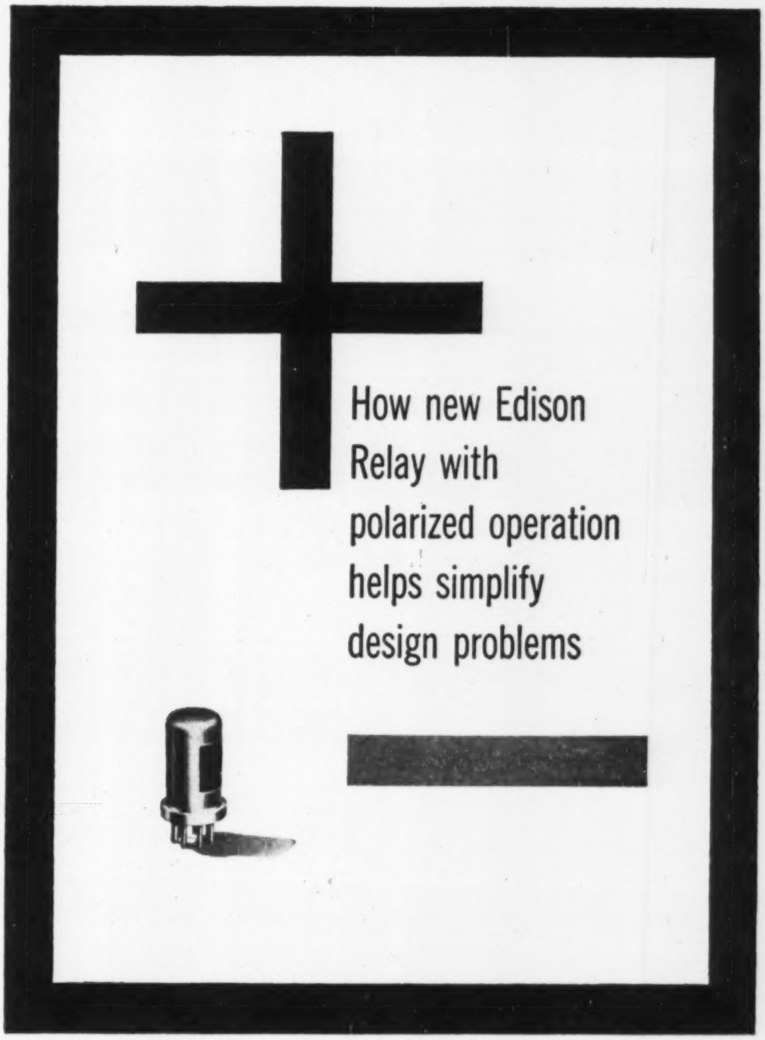
Sweep Generator

New "Model #780" is said to be the first all-electric sweep generator of high accuracy and stability available at moderate cost, a desirable instrument for any electronics lab and production line as well as a must for TV service technician. Features: complete electronic circuits (no motors or moving parts), unique unidirectional coupling-sweeps, multiple-shielded push-button attenuator-detector/comparator output.—*Radio City Products Co., Easton, Pa.*

For more information circle **302** on inquiry card.

Mismatch Units

New "FXR Type X510" Standard Mismatch Units, for determining absolute accuracy of microwave VSWR equipment, have an absolute accuracy of better than 1 percent; termination


How new Edison Relay with polarized operation helps simplify design problems

Current flow deflects the rotor of Edison's Sensitive Magnetic Relay in a direction determined by current polarity. Changing the operating current gradually causes the moving contact to follow the rate of change until it touches one of the stationary contacts. This basic operation adapts the Edison Relay for use as a null detector in a bridge circuit – and as a sensing element in a contactor servo circuit.

For designers of electronic equipment, Edison's Sensitive Magnetic Relay – a product of the world-famous Edison Laboratory—offers other outstanding features:

▶ **Low power operation** – Standard types close on input currents as low as 30 microamperes – available in special circumstances for even lower current.

▶ **Versatility** – Interchangeable coils can be supplied with resistances from 0.5 to 23,000 ohms. Normal closing power may be increased 10,000 times without adverse effects.

▶ **Contacts** – Platinum-iridium wire, either SPST or SPDT, with capacity of 1/3 ampere at 28 volts D.C. non-inductive.

▶ **Stability** – Test relays have exceeded 8,000,000 cycles without calibration change.

▶ **Shock and vibration resistant** – Relay will withstand shock of 50 g's in all planes without damage.

Write us for complete data on this new Edison development.

Thomas A. Edison

A GREAT NAME CONTINUES GREAT NEW ACHIEVEMENTS

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For more information circle **54** on inquiry card.

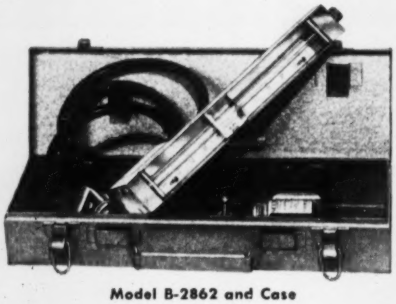
Buying or Selling
...Rely on
MERIAM
MANOMETER
ACCURACY

In custody transfer of valuable liquids or gases, greatest possible accuracy is required by both buyer and seller. Field measuring equipment must be precisely calibrated often. For this purpose Meriam Manometer Models B-2856 and B-2862 are extensively used.

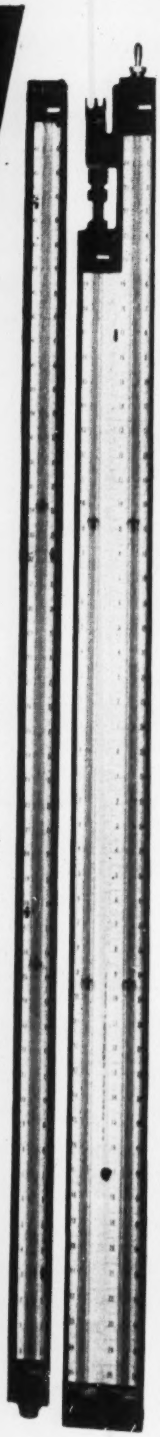
The new, lightweight (twenty pounds) Meriam Model B-2856 Sectional U-Type Manometer in 100″ range using water offers the extreme accuracy and sensitivity required for calibration. All-aluminum construction, this model can be "broken" to 50″ length for carrying convenience. Interpolated readings to .025″ water available.

The Meriam Model B-2862 Portable Field Manometer is the pioneer instrument for field calibration service. Designed with precision bore tubing, glass coated well, magnifier with anti-parallax device and a universal mounting bracket, this model in ranges up to 310″ water using mercury, offers a new high in utility and accuracy.

If you have a problem involving field calibration, drop us a line or call your Meriam Technical Representative. The Meriam Instrument Company, 10958 Madison Avenue, Cleveland 2, Ohio.



Model B-2862 and Case



Model B-2856

MERIAM
Instruments
ESTABLISHED 1911

MANOMETERS, METERS AND GAUGES FOR THE ACCURATE MEASUREMENT OF PRESSURES, VACUUMS AND FLOWS OF LIQUIDS AND GASES

For more information circle **55** on inquiry card.

movable over more than one-half guide wave-length to allow compensation for small residual mismatch.—*Electronics & X-Ray Div., F-R Machine Works, Inc., 26-12 Borough Place, Woodside 77, N. Y.*

For more information circle **303** on inquiry card.

S-Sb. Generator

New "Model 51 SB" single sideband generator is especially designed for operation with maker's "Model 5100 Transmitter." Tuning and operation are fast and uncomplicated. No test equipment is required. Among "extras"; voice-operated and push-to-talk controls, speaker deactivating circuit, TVI suppression, and unitized construction for quick and easy removal of any major section.—*Barker & Williamson, Inc., 237 Fairfield Avenue, Upper Darby, Pa.*

For more information circle **304** on inquiry card.

Electronic Switch

New "Type 330" converts any c-r. oscilloscope in range of d-c. to 15 Mc. into a dual-trace unit; may be triggered from 'scope-gate output at rates from 0 to 100 kc. or will switch at recurrent rates of 1, 10, or 100 kc.—*Allen B. Du Mont Labs, Inc., 760 Bloomfield Ave., Clifton, N. J.*

ELECTRONIC SWITCH

For more information circle **305** on inquiry card.

Pulse Generator

New "Model 4120A" is a low-cost highly versatile unit capable of repetition rates from 30 cps. to 300 kc. in 4-decade steps, variable pulse width from 0.2 usec. to 100 usec. in 2 ranges; variable pulse delay from 1 to 100 usec. in 2 ranges; positive sync trigger pulse available for reference.—*Electro-Pulse, Inc.,* 11811 *Major St., Culver City, Calif.*

For more information circle **306** on inquiry card.

UHF-VHF Baluns

New "Model V-6A" balun is designed to match an unbalanced 50-ohm source to a balanced 300-ohm load with negligible loss and good balance efficiency over 50-220-Mc. range. "V-6B" is similar but designed for a source impedance of 75 ohms. "Model U-2A" matches a 50-ohm unbalanced source to a balanced 300-ohm load over 450-900-Mc. range. "U-2" is similar but designed for a source impedance of 75 ohms.—*Linear Equipment Labs., Inc., Brightwater Pl., Massapequa, L. I., N. Y.*

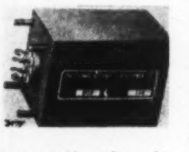
For more information circle **307** on inquiry card.

VHF-UHF Reflection Box

New VHF-UHF Reflection Box simplifies measurement of tuner reflection coefficient, in conjunction with a linear balun, enables simple visual observation of ability of a tuner to provide a proper match to a 300-ohm transmission line over VHF and UHF TV bands.—*Linear Equipment Labs., Inc., Brightwater Pl., Massapequa, L. I., N. Y.*

For more information circle **308** on inquiry card.

Demodulator

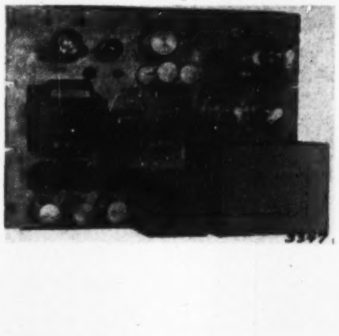


New "Type 808" phase-sensitive demodulator produces a full-wave reversible-polarity dc. voltage output for a reversible-phase ac. voltage input; will also function as a modulator, producing an in-phase ac. output of carrier frequency that is proportional to dc. voltage input. Suited for feeding a dc. controlled mag. amp. from an ac. signal source; also as lead or stabilizing network for servo systems.—*Polytechnic Research & Development Co., Inc.,* 202 *Tillary St., Brooklyn* 1, *N. Y.*

For more information circle **309** on inquiry card.

Amplitude Modulator

New wide-band amplitude modulator, having extremely low distortion, is suitable for use in applying complex-wave high-level plate modulation to Class C r-f. amplifiers. Standard



JANized
RAKSCOPE
by Waterman

MODEL S-12-B

USES ONLY 7" OF STANDARD RELAY RACK

ANOTHER EXAMPLE OF Waterman PIONEERING...

The S-12-B RAKSCOPE is a rack mounted, JANized (Gov't Model No. OS-11) version of the famous WATERMAN S-11-A POCKETSCOPE, with the addition of a triggered sweep and a special calibrating circuit for rapid frequency comparisons. The entire oscilloscope is built to occupy but seven inches when mounted in a standard relay rack. The vertical and horizontal amplifiers are identical, having sensitivities of 0.05 Volt rms/inch and frequency responses which are flat within −2 db from DC to 200 KC. These features permit observation of low frequency phenomena without undesirable trace bounce. The sweep rate is continuously variable from 5 cycles to 50 KC in either the triggered or repetitive mode with synchronization polarity optional. The return trace is blanked. Because provisions are made for applying input signals from the rear, as well as the front, the S-12-B is the ideal combination, systems monitor and trouble-shooting oscilloscope. Investigate the multiple applications of this instrument as an integral part of your "rack mounted" projects.

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PHILADELPHIA 25, PA.
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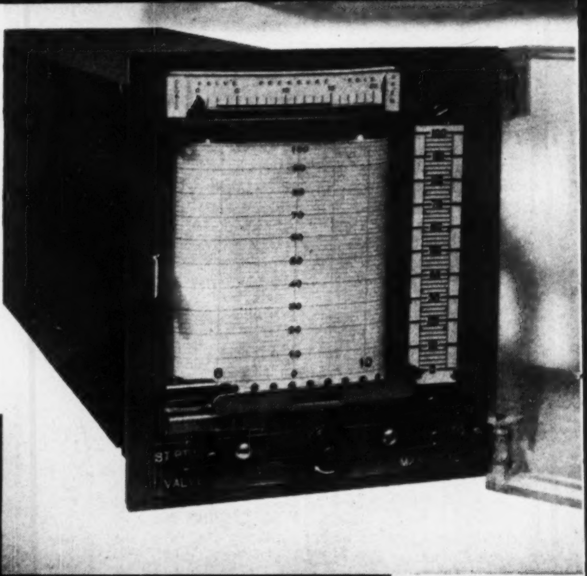
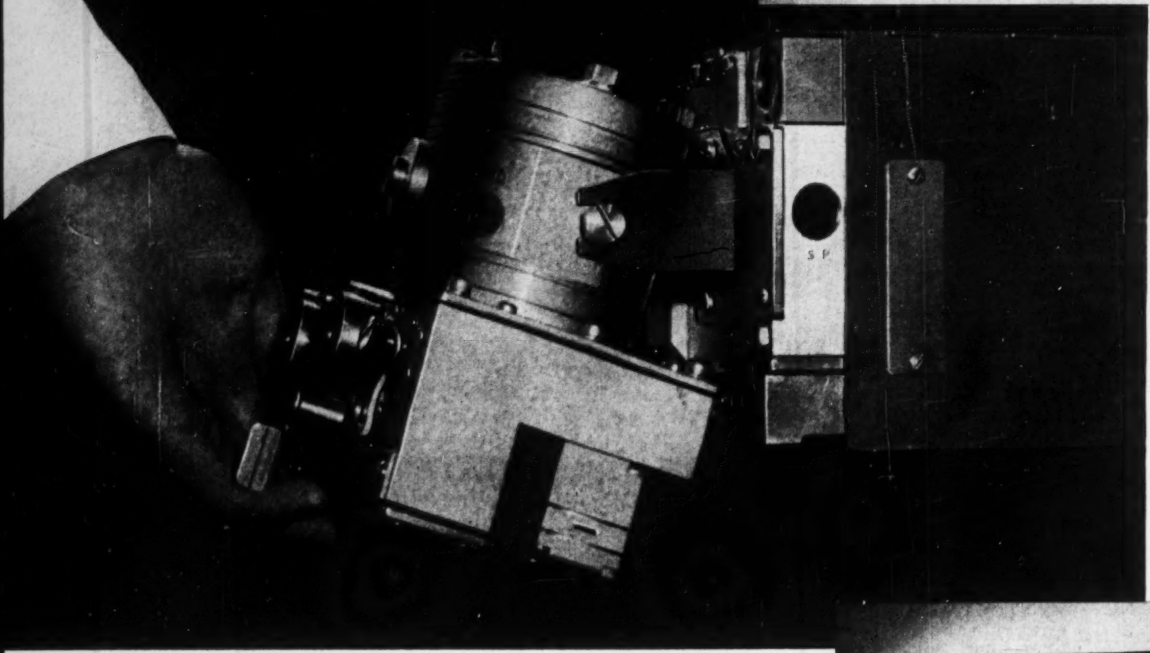
S-5-A LAB PULSESCOPE
S-6-A BROADBAND PULSESCOPE
S-11-A INDUSTRIAL POCKETSCOPE®
S-12-B JANized RAKSCOPE®
S-14-A HIGH GAIN POCKETSCOPE
S-14-B WIDE BAND POCKETSCOPE
S-15-A TWIN TUBE POCKETSCOPE
RAYONIC® Cathode Ray Tubes and Other Associated Equipment

For more information circle 56 on inquiry card.

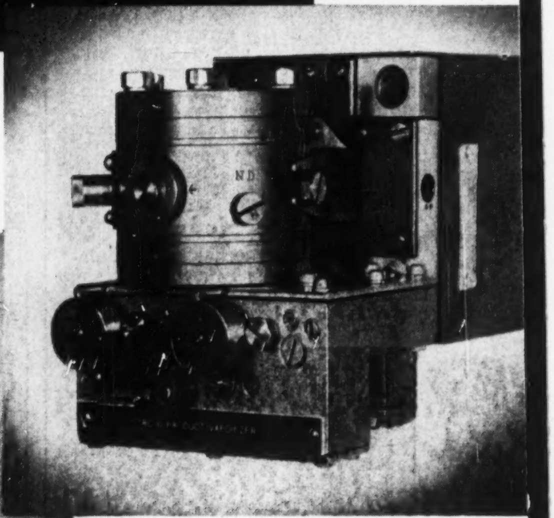
Horizontal scale above chart provides continuous indication of control air pressure to valve.

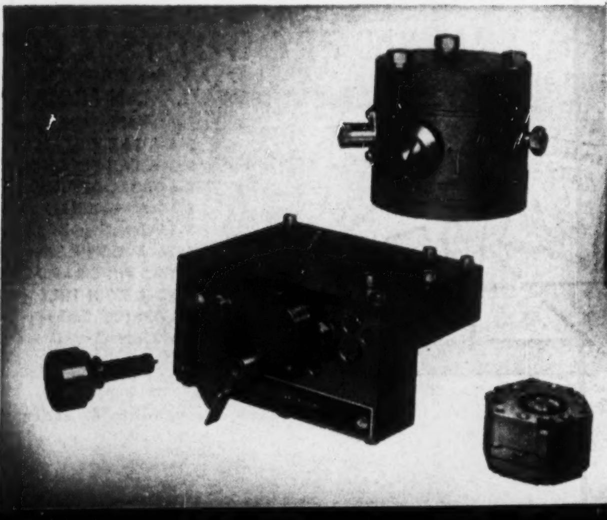


Quick-connect controller mounting . . . for added protection the controller is supported by a yoke when disconnected.



All adjustments are readily accessible from the rear of the controller.





Unitized construction of all major components simplifies maintenance . . . makes reassembly foolproof.

For more information circle **57** on inquiry card:

Today's Tel-O-Set* instruments are easiest to install . . . operate . . . service

The latest improvements in the *Tel-O-Set* family of miniature recorders and controllers make them the simplest and most convenient ever. Operating men, installers and service men alike will appreciate these outstanding features:

Quick-connect mounting—either on back of recorder, back of panel, or at a remote location. A single lever opens or closes all interconnecting air lines . . . allows the controller to be removed without interfering with manual control of the process.

Foolproof connect and disconnect. The rear of the recorder is a flat gasketed surface that matches up perfectly with the controller. It's completely free of any protruding valve stems or plug-in fittings that might be damaged in shipping or handling in your plant. Self-contained air switch must be shut off before the controller can be removed.

Leakproof design—with large capacity valves.

Wide range of reset rates. A single instrument provides a simple choice of three different ranges . . . fast, intermediate and slow . . . enabling one basic model to serve in applications formerly requiring several models.

Versatility. Rate action is readily added. When equipped with a manifold, the controller can be mounted remotely, either back of the panel or in the field.

Low air consumption—less than 0.2 scfm.

Unitized construction—permits fast, easy removal and replacement of major sections.

Compare the features . . . and the operating characteristics . . . of the *Tel-O-Set* line of instruments. You'll find they represent the top in value in miniature instrumentation, that will give you the top in performance and serviceability on your process control panels. For a discussion of your specific requirements, call your nearby Honeywell sales engineer . . . he's as near to you as your phone.

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Industrial Division, Wayne and Windrim
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● **REFERENCE DATA: Write for your copy of new Bulletin No. 7201, "Quick-Connect *Tel-O-Set* Instruments."**

**Tel-O-Set* is a trade mark of the Minneapolis-Honeywell Regulator Co.

H HONEYWELL

MINNEAPOLIS
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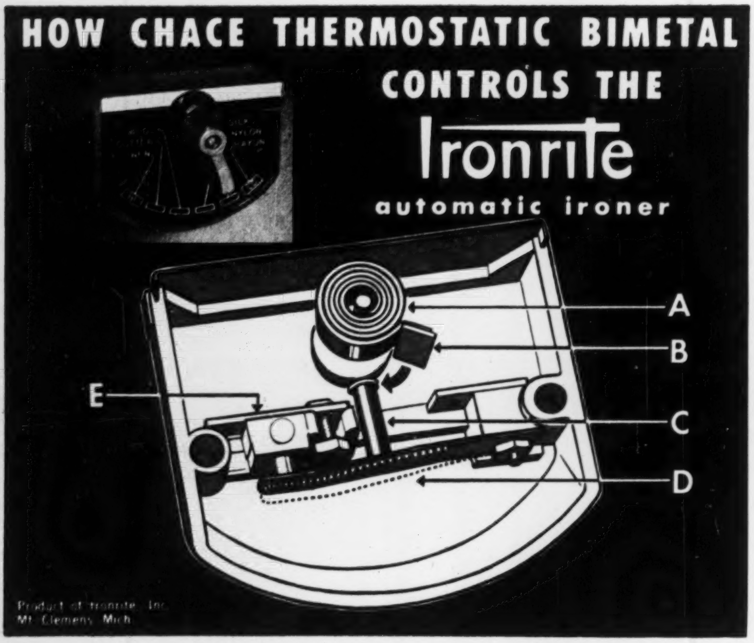
BROWN INSTRUMENTS

First in Controls

For more information circle **57** on inquiry card.



Ironrite Automatic Ironers are designed from a functional as well as an aesthetic viewpoint, their chief advantage being speedy, efficient ironing of all materials in almost any shape or form. Simplicity of operation and control are some of the Ironrite Automatic Ironer's foremost features. Of course, for safe, foolproof regulation of temperatures for ironing different fabrics, the Ironrite depends upon Chace Thermostatic Bimetal.

The control switch shown in the illustration is simply, quickly set for temperature variations by moving the indicator to the correct temperature shown for various materials. Whenever the ambient temperature attains the maximum, things begin to happen. A coil of Chace Thermostatic Bimetal (A) rotates, forcing plate (B) against post (C). This leverage bends the circuit connector (D), breaking the circuit at (E) until the ambient temperature is lowered. When the indicator is set for low temperatures, the coil is adjacent to the post and has less distance to move to break the circuit. At high temperature settings the coil is at its extreme distance from the post and requires a greater amount of heat to break the circuit.

Chace Thermostatic Bimetal is available in 29 different types, in strip, rolls or in completely fabricated assemblies made to your specifications. Before development of your new controlling, indicating or protecting device, read our booklet "Successful Applications of Chace Thermostatic Bimetal." Write for your free copy of this valuable engineering data today.

IT BENDS WITH THE HEAT
W. M. CHACE CO.
Thermostatic Bimetal
1609 BEARD AVE., DETROIT 9, MICH.

For more information circle **58** on inquiry card.

models available for modulating up to 400 watts power input to Class C. High power units on special order.—*McIntosh Electronics Co., 5232 River Rd., Washington 16, D. C.*

For more information circle **310** on inquiry card.

Marker Generator

New crystal-controlled "Microsecond Marker Generator" provides a standard for calibrating sweep speed and sweep linearity of oscilloscope time

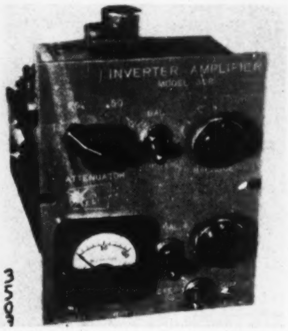
bases; is especially useful to modernize older 'scopes. Feature is complete absence of adjustments, whence simplicity of operation said to be "found in no other marker generator."—*M.A.D. Associates, Box 177, Endicott, N. Y.*

For more information circle **311** on inquiry card.

AMPLIFIERS

D-c. Amplifiers

New "Model 306 Series," for use with galvanometer oscillographs, etc., invert d.c. and amplify resultant a.c.



Power unit available for 24 v.dc. or 110 v.ac., 50 cps.—*Allegany Instrument Co., 1000 Oldtown Rd., Cumberland, Md.*

For more information circle **312** on inquiry card.

Color-TV-line Amplifier

New "Model LA-2," for transmission and distribution of color TV video signals in lab and on production line, will deliver several times output of B&W line amplifiers at less than 5 percent compression, permitting simulation of color receiver detector output; has polarity-reversing switch, regulated power supply and input-output termination connectors.—*Linear Equipment Labs., Inc., Brightwater Pl., Massapequa, L. I., N. Y.*

For more information circle **313** on inquiry card.

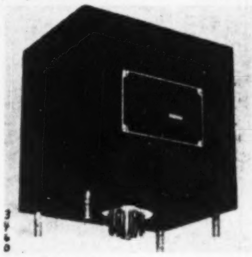
Ten-watt Amplifier

New "Model 910" ten-watt amplifier for hi-fi reproduction is of Williamson type; frequency response 20 to 30,000 cps. at ±1 db; total harmonic distortion less than 0.5 percent at full rated output; hum and noise level 80 db below rated output.—*Freed-Eisemann, 200 Hudson Street, New York 13, N. Y.*

For more information circle **314** on inquiry card.

Magnetic Amplifier

New "SMA 4-103" operates on 115 volts, 400 cps.; input impedance 10,000 ohms; input signal a.c., d.c. or pulse; phase-reversible output; approx. 50,000 power gain (@ 0.5v signal); response time approx. 1/200 sec.; standby power 12 watts; continuous duty cycle. Designed for use in servo systems employing 2-phase 400-cps. low-inertia induction motors. —*Ketay Mfg. Corp., 555 Broadway, New York 12, N. Y.*

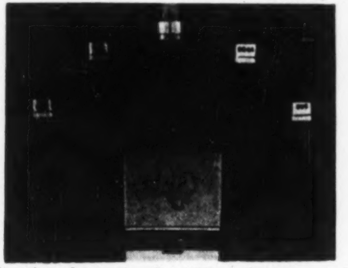


For more information circle **315** on inquiry card.

ELECTRICAL AND ELECTRONIC COMPONENTS

Silicon Transistors

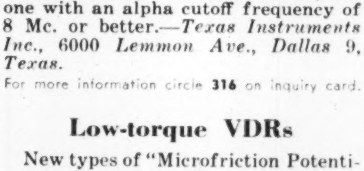
New expanded line of silicon transistors comprises five types, one new model with an alpha (current amplification factor) of 0.975 or better, and one with an alpha cutoff frequency of 8 Mc. or better.—*Texas Instruments Inc., 6000 Lemmon Ave., Dallas 9, Texas.*

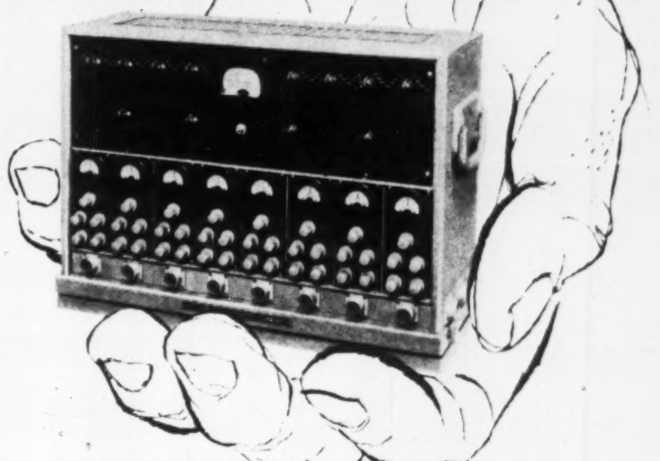


For more information circle **316** on inquiry card.

Low-torque VDRs

New types of "Microfriction Potentiometers" (made by Ohmag in Switzerland) include single- and multi-section





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All the features you have ever dreamed of conveniently packed in one small unit...

THE NEW HATHAWAY MRC-21

6, 8 or 12 channels complete in one unit for airborne, mobile or laboratory applications.

Carrier-type amplifiers (response 0-1500 cps) . . . or

Wide-band amplifiers (response 2-6000 cps).

AND THINK of all these features:

❶ Interchangeable amplifiers, carrier or wide-band covering range of **0-6000 cps**

❷ Unbelievable insensitivity to shock or vibration

❸ The most convenient arrangement of controls you ever saw

❹ Highly accurate and stabilized

❺ Internal carrier power supply

❻ Automatic calibration, with different value of strain in each channel if desired, **just by pressing a button!**

❼ Output current swing of 200 millimeters, **no more galvanometer troubles**

❽ Indicator for balance and strain **on each channel**

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For more information circle **59** on inquiry card.

DIALCO

Sub-Miniature PILOT LIGHTS

A great aid to miniaturization

Require a single 15/32" hole

All lens colors

All units applicable to Mil Specifications

when you're CRAMPED for SPACE

A. PLASTIC PLATE LIGHT ASSEMBLIES

B.

A) No. TT-51; No. TT-51A with No. 327 lamp. For edge lighting. Red or other color filters, black top.
B) No. 8-3730-111; for Mil-7788 panels.
C) No. 4-1930; light shield.
D) No. 8-1930-111; non-dimming.
E) No. 11-1930-111; mechanical dimmer. No. 3-1930-111; polaroid dimmer.

All assemblies accommodate midget flanged base lamps like this one (*actual size*); easily replaced. Available for voltages of 1.3, 2.7, 6, 14, and 28.

Any assembly available complete with lamp.

SAMPLES ON REQUEST — NO CHARGE

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C. LIGHT SHIELD ASSEMBLY

D. E. SUB-MINIATURE INDICATOR LIGHTS

(All illustrations are approx. actual size.)

Foremost Manufacturer of Pilot Lights

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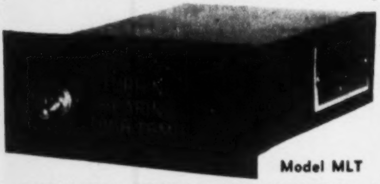
60 STEWART AVE. • BROOKLYN 37, N. Y.
HYACINTH 7-7600

For more information circle **60** on inquiry card.

KIRKLAND ALARM UNITS

MODERN SUPERVISION



Model MLT

FLUSH TYPE HOUSING FOR MOUNTING IN A SINGLE OPENING IN A PANEL. Face plate 5" x 2¼"

COMPLETE SELF-CONTAINED ALARM UNIT WITH LAMPS, RELAYS AND SWITCH, FACTORY WIRED AND READY FOR USE.

Model VIG IS A WIRING DEVICE THAT MOUNTS ON A STANDARD OUTLET BOX. PLATE IS 4½" Sq.

VISUAL AND AUDIBLE ALARMS

MANY INTERESTING SERVICES AVAILABLE, for example our #200. When the contacts become abnormal, red and green lamps light and audible signal sounds, switch operation removes audible signal and only red lamp remains lighted. When contacts restore to normal, the audible signal sounds automatically and only green lamp is lighted. Switch operation silences acknowledgment audible signal and all lamps are darkened. ALL STANDARD ANNUNCIATOR SERVICES AVAILABLE.

Write for New Catalog

THE H. R. KIRKLAND CO.
MORRISTOWN, N. J.

For more information circle **61** on inquiry card.

PYROMETER INSTRUMENT COMPANY

New Plant & Laboratory

Bergenfield 34, New Jersey

Manufacturers of Pyro Optical, Radiation Immersion and Surface Pyrometers for over 25 years.

The Simplified PYRO Optical Pyrometer

PYRO Optical Pyrometer is the only self-contained, direct reading, light-weight and dependable unit for quick and accurate high temperature measurements. Unique construction permits determinations even on MINUTE SPOTS, FAST MOVING OBJECTS or of the SMALLEST STREAMS. Special Foundry Type and Universal Triple Range have an additional Red Scale for direct readings of the true spout and pouring temperatures of molten iron, steel, monel, etc. when measured in the open. Stock ranges from 1400°F to 7500°F or in equivalent Centigrade calibrations. Ask for free Catalog No. 85 for complete details.

Free literature also available on PYRO Surface, Indicating, Radiation and Immersion Pyrometers.

For more information circle **62** on inquiry card.

units for exacting applications such as remote measurement and control, computers, servomechanisms, facsimile, research, etc.—*American British Electric Corp., 57 Park Ave., New York 16, N. Y.*

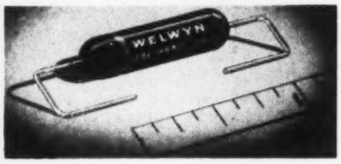
For more information circle **317** on inquiry card.

Stepless VDR

New "Model 85175 Spiralpot" 4-oz. infinite-resolution slide-wire voltage-dividing resistor, 1½ in. diam., is available in 3-turn or 10-turn models, with resistance ranges of 6 to 2500 ohms, and linearities of 0.1 percent and 0.05 percent; rating 5 watts for a 10-turn unit; torque 2 oz-in. or less. —*G. M. Giannini & Co., Inc., 918 E. Green St., Pasadena 1, Calif.*

For more information circle **318** on inquiry card.

Insulated Resistors



New "Welwyn" insulated deposited carbon resistors feature stability, tolerance, noise, and other performance quality characteristics equal to standard "Welwyn" deposited carbon line. New insulating material permits encapsulated resistor to withstand 8000-v. applied potential without flashover or breakdown. Available in ¼, ½, 1 and 2 watt ratings.—*Rockbar Corp., 215 East 37th St., New York 16, N. Y.*

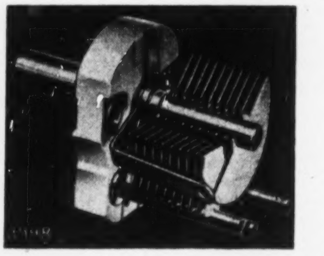
For more information circle **319** on inquiry card.

Carbon-film Resistors

New improved "Stemag Chemo-Carbon Resistors" are said to offer many advantages including small temperature coefficients, stability when exposed to humidity, stable resistance values, low noise level, and uniformity on large production runs. "Capless Type A" is said to be "the most economical resistor of its type available." "Precision Cap Type D" meets MIL-R-10509A, features 1.0 to 0.5 percent tolerances.—*Arnhold Ceramics Inc., 1 E. 57th St., New York 22, N. Y.*

For more information circle **320** on inquiry card.

Variable Capacitors



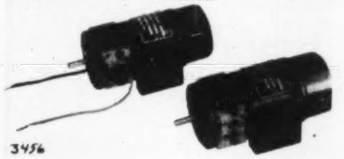
New "APC" and "MAPC" variable capacitors with extended shafts are now available with ½-in. shaft extension for knob control.—*Hammarlund Mfg. Co., 460 W. 34, N. Y. 1, N. Y.*

For more information circle **321** on inquiry card.

ELECTROMECHANICAL COMPONENTS

PM D-c. Motors

New high-performance d-c. motors and tachometer-generators, permanent-magnet type, weigh under 20 oz.;

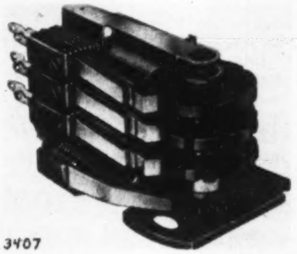


1/30 to 1/100 hp. on voltages from 6 to 27.5 and from 3000 to 9000 rpm.; tachometer-generator outputs from 0.46 to 2.4 vdc. per 100 rpm. up to 9000 rpm.—*Instrument Motors, P.O. Box 5, Acosta St., Stamford, Conn.*

For more information circle **322** on inquiry card.

Cam-type Relay

New "Series OCS" cam-type rotary relay can replace banks of relays, or combinations of relays and stepping switches; is said to be exceptionally



resistant to shock, vibration, and temperature changes. Test records show over 250,000,000 high-speed operations.—*Automatic Electric Sales Corp., 1033 W. Van Buren Street, Chicago 7, Ill.*

For more information circle **323** on inquiry card.

Subminiature Relay

New "BR-1" relay was developed to improve reliability of a radio guidance equipment. Although it is a sensitive relay, it can handle a ¼-kw. heat lamp on 110 v.a.c. and pulse at 10 cps. with this load connected. It handles 8 amps. for 1000 operations; maker has "never managed to find the total life at the rated contact current of 2 amps." Samples for immediate shipment are said to be ideal for operation in plate circuit of small triodes or pentodes. —*Babcock Radio Engineering, Inc., 7942 Woodley Ave., Van Nuys, Calif.*

For more information circle **324** on inquiry card.

Synchros

New series of Size 11 synchros feature high accuracies available previously only in larger units. Max. diam. 1.062 in.; max. over-all length 1.702 in.; weight 3.1 oz.; supplied with leads, or can be specially ordered with radial or axial terminals. Avail-

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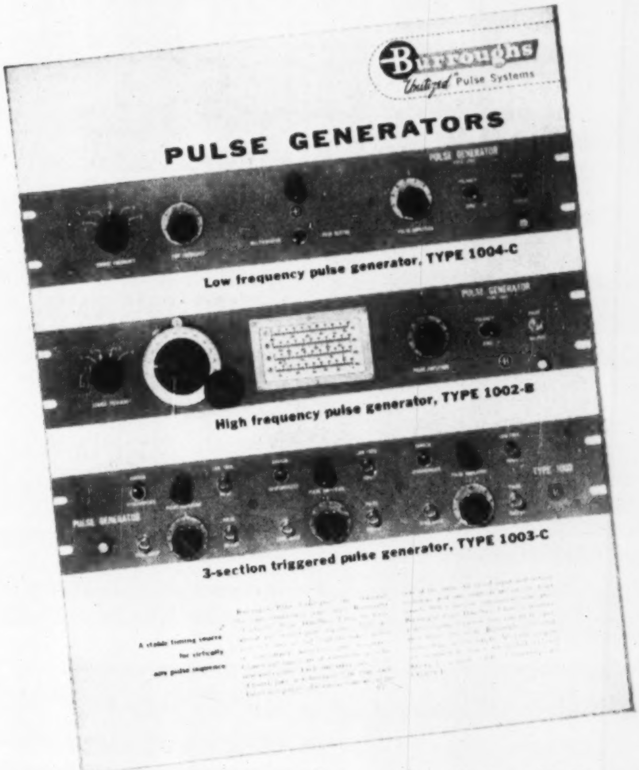


Burroughs "Unitized" Pulse Systems

PULSE GENERATORS

Low frequency pulse generator, TYPE 1004-C

High frequency pulse generator, TYPE 1002-B

3-section triggered pulse generator, TYPE 1003-C

...read how Burroughs Pulse Units can save you weeks of engineering time

This new, free brochure shows by actual examples how you can assemble even complex pulse systems simply by connecting together matched Burroughs Pulse Units that perform basic functions.

You save weeks of breadboard engineering and can begin immediately on your primary engineering project. All your time can be spent designing commercial products—none lost designing test equipment. Because Burroughs Pulse Units are so easy to use, you can do many jobs you might otherwise never get time to do at all.

Prove to your management just how much engineering cost Burroughs Units can save for you. Without charge, we'll engineer a system to meet one of your current problems and let you compare the cost. Write for your free copy of the new brochure. Burroughs Corp., Electronic Instruments Div., Dept. 5M, 1209 Vine St., Phila. 7, Pa.

EASY AS THIS TO ASSEMBLE A PULSE SYSTEM WITH BURROUGHS PULSE UNITS

1. Prepare a time chart of the desired pulse sequence.

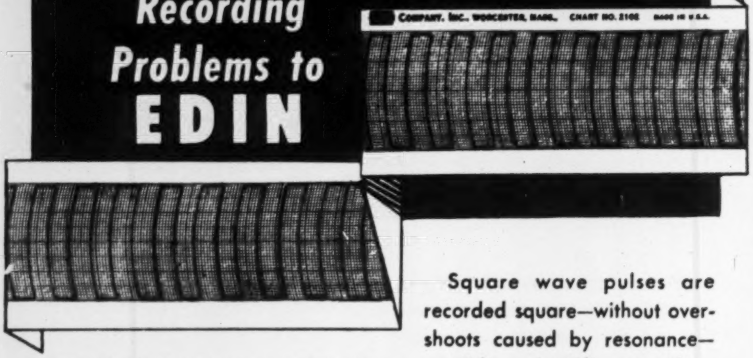
2. Draw a block diagram and determine which units you need.

3. Connect the units together with standard coaxial cables.

ELECTRONIC INSTRUMENTS DIVISION
Burroughs
FIRST IN PULSE HANDLING EQUIPMENT

For more information circle **63** on inquiry card.

Turn Over Your Square Wave Recording Problems to EDIN


COMPANY, INC., WORCESTER, MASS. CHART NO. 2108 MADE IN U.S.A.

Square wave pulses are recorded square—without overshoots caused by resonance—on Edin scientific recording equipment.

For assistance in the selection of equipment for any graphic recording task, there is an Edin representative nearby, anxious to serve you. Tell us you would like to see him.

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Position

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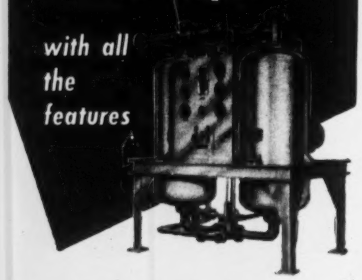
For more information circle **64** on inquiry card.

The Instrument Air Dryer with all the features



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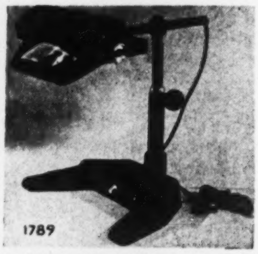
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For use in gear inspection . . . fine parts inspection, printing, engravings, fine assembly work, fine paintings, fine machine work, lathe work.

Check These Exclusive Features
- Large clear field—6½" x 2½" Plane convex
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- Tilts to any angle
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- 2 fluorescent 12-watt lamps

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For more information circle **66** on inquiry card.

able in these types: signal generators, receivers, control transformers, control differentials, resolvers, and sine-cosine generators.—*Clifton Precision Products Co., Inc., Marple at Broadway, Clifton Heights, Penna.*

For more information circle **325** on inquiry card.

Terminal-connector Strip

New "No. 3372" female mating strip, for permanent base mounting and to be used with male connectors "Nos. 3367 and 3369," has fifteen pressure type sockets of beryllium copper; nominal creep of 3/32-in.; solder tabs for No. 20 wire; gold plating over silver.—*H. H. Buggie, Inc., 726 Stanton St., Toledo 4, Ohio.*

For more information circle **326** on inquiry card.

MECHANICAL COMPONENTS

Ten-turn Counting Dial

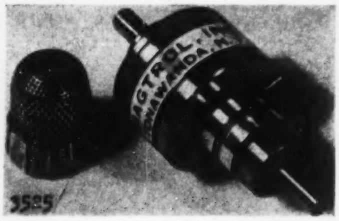
3798

New "Model 1301 Microdial" is a direct-reading dial for any manual or servo-motor-operated multiturn rotating device of 3600 degrees or less. Shaft or wiper position is indicated to 3 places (turns, tenths and hundredths) in highly-legible numbers behind a glass-covered window, facilitating wide-angle observation and minimizing error in forced fast reading. New dial may be operated at speeds up to 100 rpm.; its accuracy is 1 part in 1000. It also can be used as a percentage counter as it indicates increments of 0.1 percent. —*Borg Equipment Div. The George W. Borg Corp., Janesville, Wis.*

For more information circle **327** on inquiry card.

Miniature Clutch

New "Magtrol Micro-Clutch," designed to meet limited space requirements in aircraft and guided missile instrumentation, etc., is available as a clutch and a clutch brake; over-all length 2⅛ in. including both shaft extensions; capable of transmitting 8 oz.-in. torque with 65-ma. control current.—*Joe Davidson and Associates, P. O. Box 108, South Gate, Calif.*

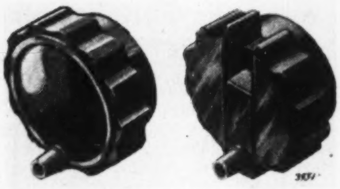


3525

For more information circle **328** on inquiry card.

Clutch Knobs

New "Controlled Torque" knobs for multi-turn devices safeguard instruments against careless cranking beyond normal stops; work on principle

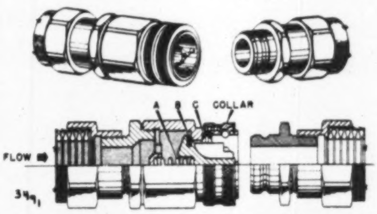


of slip clutch; have spinners for rapid setting. Also available without slip clutch.—*Jan Hardware Mfg. Co., Inc., 75 N. 11th St., Brooklyn 11, N. Y.*

For more information circle **329** on inquiry card.

Hose Couplings With Built-in Check Valves

New complete line of maker's quick-seal, leak-proof hose couplings fea-

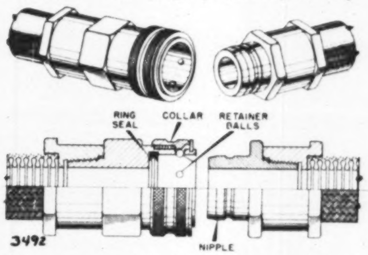


tures built-in single or double check valves.—*Titeflex, Inc., 500 Frelinghuysen Ave., Newark 5, N. J.*

For more information circle **330** on inquiry card.

Heavy-duty Couplings

New heavy-duty models of maker's quick-seal leak-proof coupling are available for high-pressure, heavy-



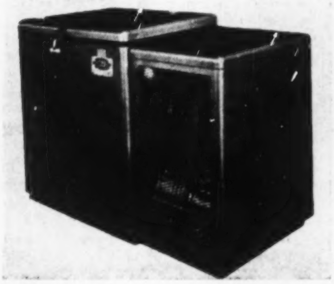
flow applications in steel, oil, chemical, construction, and other industries.—*Titeflex, Inc., 500 Frelinghuysen Ave., Newark 5, N. J.*

For more information circle **331** on inquiry card.

MISCELLANEOUS

Liquid or Gas Chillers

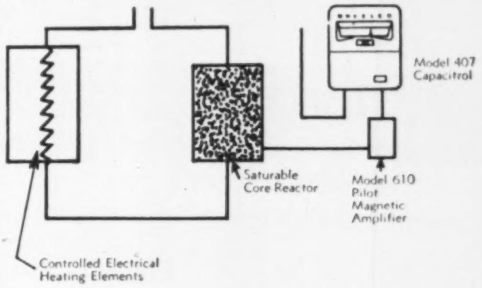
New liquid or gas chillers reduce temperatures to as low as –130 F.; include portable models in a range of



NEW Wheelco Model 407 Capacitrol

More sensitive and flexible temperature controller

WHEELCO
400
800
1200
1600


Model 407 Capacitrol
Saturable Core Reactor
Model 610 Pilot Magnetic Amplifier
Controlled Electrical Heating Elements

You'll like the extra *sensitivity* and *flexibility* of this great new Wheelco Controller. Fully "plug-in," it gives you a wide choice of control forms quickly and easily arranged by interchanging packaged control chassis. Model 407 chassis, for example, provides a true proportioning system that smoothly and *steplessly* proportions *electrical power* input in accordance with system demands. Variations in output of the Capacitrol proportion output to a saturable core reactor so power supplied is *always proportional* to demands of the sensing unit. Easily applied to a variety of continuous process jobs. Assures maximum dependability and accuracy, plus striking new design features never before combined in *one* instrument. For information on other control forms available, write for Bulletin F-6314.

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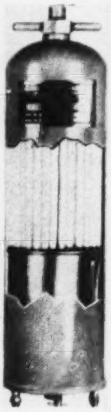
Eastern Representative: Aero Engineering Inc.

For more information circle **68** on inquiry card.

0.5 to 7.5 hp.; also remote chillers in capacities to 200,000 Btu. per hour and up to 100 hp. depending on temperatures needed.—*Conrad Inc.*, 183 *Jefferson Ave., Holland, Mich.*

For more information circle **332** on inquiry card.

Air Dehydrators and Filters



Two new models ("M-30" and "M-100") of "Condensifilter" for dehydrating and filtering compressed air are rated at 30 and 100 scfm. respectively, at line pressure of 100 psig. Both models feature a condenser to reduce compressed air dewpoints, plus a disposable filter cartridge for removing solid particles. All sealing is with "O" rings, obviating need for tools to dismantle units for service. — *Hankison Corp.*, 951 *Banksville Rd.*, 194 *Biltmore Bldg., Pittsburgh* 16, *Penna.*

For more information circle **333** on inquiry card.

Static-control Systems

New "TAKK High Speed Static Control Systems" incorporate a new resistance material which makes possible more effective control of charges on high-speed industrial processing operations, and gives a higher margin of safety on use in hazardous areas. Full control of charges is also maintained over a longer period.—*The Hewson Co., Inc.*, 443 *Broad St., Newark* 2, *N. J.*

For more information circle **334** on inquiry card.

Transit-Level

New "Model 65" (made by Brunson Instrument Co.) is said to incorporate many advantages of construction and accuracy hitherto limited to engineers' transits costing nearly three times as much: dustproof ball-bearing center and telescope axis sealed in with "lifetime" silicone grease; size variations of balls do not exceed half a wavelength of light; 20-power telescope completely sealed against dust and resistant to moisture-condensation; coated optics; internal focus precisely collimated from 3 ft. to infinity. Distributed exclusively through *Charles Bruning Co.*, 4700 *Montrose Ave., Chicago* 41, *Ill.*

For more information circle **335** on inquiry card.

Automatic Static-hazard Safeguard

New "Model G-5 Safe-T-Ohm Automatic Ground Control" safeguards processing and handling of flammable materials from accumulation of electric charges. Only light beams connect power circuits to loading equipment: no possibility of a leak from power circuits charging equipment involved in loading. When resistance to ground exceeds 5 ohms, instrument prevents loading or processing of hazardous materials from being commenced or continued.—*The Hewson Company, Inc.*, 443 *Broad St., Newark* 2, *N. J.*

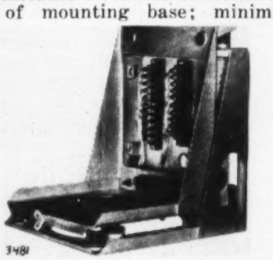
For more information circle **336** on inquiry card.

All-purpose Filters

New "Placo Self-Priming and Self-Relieving Filter Units" constructed of type 316 stainless steel, are said to be ideal for filtering all acid and alkaline solutions. They filter in depth, through cartridges of cotton, Dynel and carbon, making possible microscopic clarification, including removal of colloidal solids. No priming necessary: switch starts crystal-clear filtration at full pressure. When filter is loaded with impurities, trickle flowrate warns that cartridge needs cleaning or replacement. Capacities from 60 to 1600 gpm. Also in steel or rubber-lined models, with Worthite pumps.—*Metal Finishing Mfg. Corp.*, 89 *N. 11th Street, Brooklyn* 11, *N. Y.*

For more information circle **337** on inquiry card.

Vibration Mount With Electrical Connectors



New "Model K173 Mounting System" includes electrical connectors as part of mounting base; minimizes rocking or tipping modes; permits installation in areas where sway space is a restricting factor.—*Robinson Aviation, Inc., Teterboro, N. J.*

For more information circle **338** on inquiry card.

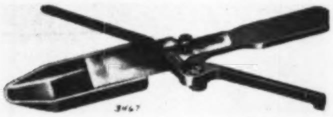
Frequency-limit Trip

New "Model 440HF" trip opens (or closes) a relay when signal frequency reaches 440 plus or minus 2 cps. Critical frequency can be predetermined to within 0.5 percent for any value of frequency between 50 and 5000 cps. Two trips can be combined in one 3 x 4 x 5-in. package to afford protection at high and low frequency limits.—*Arga Div., Beckman Instruments, Inc., South Pasadena, Calif.*

For more information circle **339** on inquiry card.

Adjustable Scoop

New adjustable scoop dispenses powders or granular material into containers. Available in complete range of sizes to dispense from 0.2 cc. to 100 cc. per fill. Each size has adjustment range of approx. 1 to 10.—*National Instrument Co., 5005 Queensbury Ave., Baltimore 15, Md.*



For more information circle **340** on inquiry card.

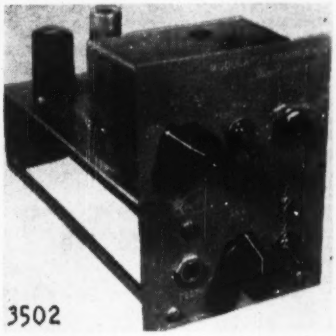
Magnetic Tape

New "Scotch" brand "Extra-Play No. 190" magnetic tape increases recording time of any tape recorder by 50 percent without decreasing tape speed or employing a larger reel; features new high-potency oxide coating only half as thick as standard coatings but with equivalent magnetic properties. Magnetic properties are virtually identical to those of "No. 111" but "No. 190" boosts response at high frequencies. Tape lengths are 900, 1800, 3600 and 7200 ft.—*Minnesota Mining and Manufacturing Co., 900 Fauquier St., St. Paul 6, Minn.*

For more information circle **341** on inquiry card.

Tape Modulator

New "Model 505" for use with magnetic tape in frequency range of d.c. to 5 kc. amplitude-modulated by 50 kc.; signal in turn modulates tape; greatly reduced cost over FM systems. Input sensitivity 1 mv.—*Allegany Instrument Co., 1000 Oldtown Rd., Cumberland, Md.*



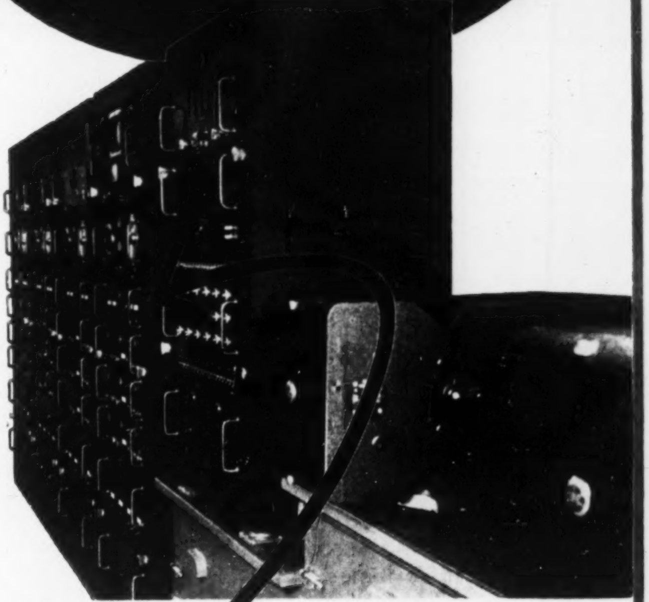
For more information circle **342** on inquiry card.

Immersion Heater

New immersion heater combines thermostatic control and safe "Corox" element. Integral thermostat control unit obviates need for a separately mounted and wired temperature regulating device. Heater converts water tank up to 110-gal. capacity to automatic electric heating, constant water temperatures in range from 120 to 180 F. Also laboratory and dairy equipment. Power ratings from 750 to 2500 watts, 118-v. or 236-v.—*Westinghouse Electric Corporation, P. O. Box 2099, Pittsburgh 30, Pa.*

For more information circle **343** on inquiry card.

Bendix-Pacific
TELEMETERING RECEIVING STATIONS



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Analog-to-digital converters, Analytical control equipment, Automatic control valves, Automatic control systems, Automatic feeding devices, Automatic gaging equipment, Automatic handling equipment, Automatic inspection devices, Automatic loaders, Automatic machine controls, Automatic tape controls, Beta ray thickness gages, Brakes, clutches and drive mechanisms, Central control systems, Color process controls, Communication systems including closed circuit television, telephone and paging systems, Compressors for automation air, Computers, analog or digital, Computer components, Continuous gas analyzers, Continuous testers, Conveyors, Counters, Data processing and data reduction systems, Data transmission and computations systems, Decade counters, Door operators, automatic, Dust and atmosphere controls, Electric motors, Electronic computers, Electronic control devices, Electronic, electrical and mechanical components for automatic production systems, Gages air, Governors, Hydraulic cylinders and motors, Indexing machines, Industrial television, closed circuit, Infrared absorption analyzers, Instrumentation and automation panels and cubicles, Instruments for measurement and control, Level controllers, Limit switches, Mass spectrometers, Metering equipment, Monitoring systems, Monorails, Motor controls, Optical gages and inspection devices, Packaged servo controls, Photoelectric control devices, Pneumatic tubes, Positioning equipment, Power supplies, Printed code readers, Radioactivity equipment, Recording equipment, Remote control systems, Scales, Scanning systems, Servo-components, Servomechanisms, Signalling equipment, Speed controls, Strain measuring devices for automatic control, Switches, relays and other electrical components, Teleprinters and facsimile recorders, Two-way radio, Ultraviolet absorption analyzers, Vibration control equipment, Weighing and proportioning equipment, Work positioning mechanisms, X-ray and fluoroscopic devices and X-ray gages.

For more information write to: The Second International Automation Exposition,
845 Ridge Avenue, Pittsburgh 12, Pennsylvania

Events . . .

Instruments and AUTOMATION

January 10

Boston Chapter, I.S.A. Meeting on Temperature Measurement and Control Equipment Exhibit, Hotel Continental, Cambridge, Mass. For information write Owen C. Jones, P.O. Box 151, Wellesley Hills 82, Mass.

January 17-19

Fourth Meeting of Conference on High-Frequency Measurements sponsored by IRE, AIEE, URSI, and NBS, Hotel Statler, Washington, D. C. For information contact F. J. Gaffney, Fairchild Guided Missiles Div., Fairchild Engine & Airplane Corp., Wyandanch, L. I., N. Y.

January 26-28

Symposium on Instrumentation for Process Industries, School of Engineering, Chemical Engineering Dept., Texas A&M College, College Station, Texas. For information write c/o Engineering School, Texas A&M.

January 27-28

Fourth Annual Instrument Short Course at Los Angeles Harbor Junior College, Wilmington, Calif. For information write J. R. Wilson, SCMA, 640 Fillmore St., Fillmore, Calif.

January 31—February 2

Sixth Annual Southeastern Instrumentation Symposium will be held on the Campus of the University of Florida. For information write W. C. Hackler, Engineering and Industrial Experiment Station, University of Florida, Gainesville, Florida.

February 7-8

Second Annual Symposium on Instrumental Analysis, sponsored by the Chicago Section, I.S.A. will be held at the Auditorium of the Western Society of Engineers, 84 E. Randolph St., Chicago, Ill. For information write Floyd Ertsman, Rm. 1420, 343 S. Dearborn St., Chicago, Ill.

February 28-March 4, 1955

Sixth Pittsburgh Conference on Analytical Chemistry and Applied Spectroscopy, William Penn Hotel, Pittsburgh. For information write J. F. Miller, Mellon Institute, 4400 Fifth Ave., Pittsburgh 13, Penna.

May 14-22

Chemical Engineering and Equipment Exhibition at Frankfort, Germany. For information write Dechema, Rheingan-Allee 25, Frankfort/M, Germany.

June 28—July 9

Third British Instrument Industries' Exposition at Earl's Court, London. For information write F. W. Bridges & Sons, Ltd., Grand Bldg., Trafalgar Square, London W. C. 2, England.

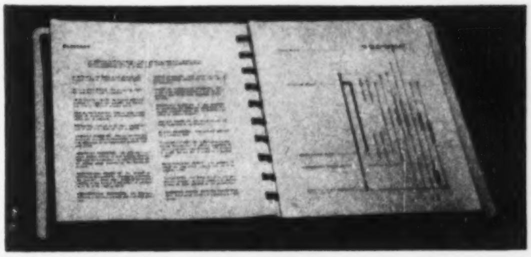
June 13-17

Annual Symposium on Molecular Structure and Spectroscopy, Ohio State University. For information write Prof. Harold H. Neilsen, Dept. of Physics, Ohio State University, Columbus 10, Ohio.

November 14-17

Second International Automation Exposition will be held at Chicago's Navy Pier. For information write The Second International Automation Exposition, 845 Ridge Ave., Pittsburgh 12, Penna.

FREE



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ON PRESSURE & VACUUM SWITCHES

As an aid in planning the vital link between your electric and hydraulic circuits, this manual contains a glossary of terms and a schematic demonstration of operating characteristics. Functions and methods are described in detail and liberally clarified with diagrams and illustrations, including symbols for circuit detailing and specification purposes. To provide the means for proper selection of a pressure switch for your specific application, a simple step by step selection chart has been developed helping you to organize your requirements in their relative order. Finally a complete run-down, illustration and tabulation of all the detail features leading to the unit that answers your specific control problem. You couldn't buy a comparable handbook.

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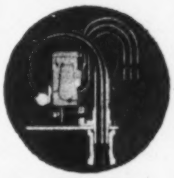
Diaphragm and Bourdon Tube Switches
Vacuum to 12,000 P.S.I.



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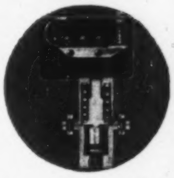
Piston Switches, Low Settings — High Proof Pressures to 15,000 P.S.I.



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ALL SWITCHES operate in any position, are not sensitive to vibration.

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For more information circle **70** on inquiry card.

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Digital Techniques and

BINARY NUMBERS

Electronic computers, multiplexing devices, diode matrices, and logical networks are based on binary numbers. Here is a clear, simple, and fundamental analysis of the meaning of numbers, the binary system, and "logical electronics." After you read this, test yourself by answering the appropriate questions in "Test Your IQ."

MARTIN L. KLEIN
North American Aviation, Inc.

ELECTRONICS AND ARITHMETIC are being mated; a new brand of electronics is coming into common use based on arithmetic. This is the electronics of logical networks.

Logical networks are used widely in computing machines and sequence-controlling devices. They perform certain operations in response to a certain set of input conditions. For example, a logical network can be designed to ring a bell if and only if a tall, blue-eyed, blonde girl passes a certain point; unless the passing individual is a girl who meets all these requirements, nothing happens. We now hear talk of logical diode matrices, flip-flops, gating circuits, multiplexing devices. To make matters worse we hear that these are based on an arithmetic of binary numbers.

We are going to show how the binary number system works. It is quite simple and has many advantages over our familiar decimal numbering system. We are going to see also how it adapts neatly to electronic circuitry, and especially the circuitry of bistable devices. With this we can arrive at a clear understanding of the many new circuits now being developed.

Number Systems

The first thing to consider is a number system. Briefly, a number system is a fixed set of marks with a rule for progressing from the given number to the next. We commonly use the decimal system, which has ten marks—0, 1, 2, 3, 4, 5, 6, 7, 8, and 9. If we write 1776 or $24.53, we have familiar numbers because of everyday experience with them. If you happen to be a Mayan Indian, these numbers would mean nothing to you because the Mayans used a five-mark counting system.

The Mayan marks quite picturesque, but for convenience we can say their numbers were 0, 1, 2, 3, and 4. A Mayan would never see the numbers 5 and over. We call the Mayan system a quinary, or five-mark, notation. Electronics has found a numbering system that is incredibly simple and, at the same time, compatible with electron-tube circuitry. It is called the *binary numbering system* and uses but two marks—0 and 1. Just why it is useful in electronics we will postpone for the moment;

Table 1. Binary Numbers with Decimal Number Equivalent

Decimal Number	*Binary Number*
0	0000
1	0001
2	0010
3	0011
4	0100
5	0101
6	0110
7	0111
8	1000
9	1001
10	1010

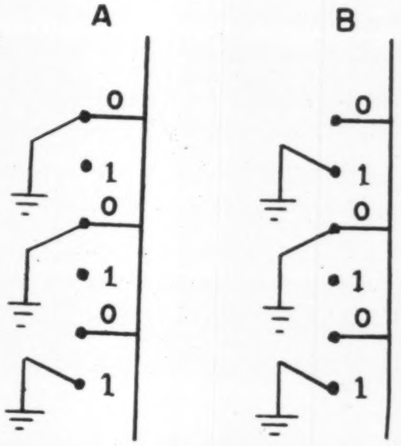

Fig. 1. Indicating binary numbers by SPDT switches. Switch setup A represents the binary number 001; switch setup B represents 101.

first let us become acquainted with this novel numbering scheme.

The Binary System

The binary system uses only two marks; for convenience they are called 0 and 1. All numbers are made up of combinations of these two numbers and no others because only two marks are allowed in the system. This gives rise to numbers of the form 101101, or 101111, or 10. What do these numbers represent in our familiar ten-mark (decimal) system, and how do we add, subtract, multiply, and manipulate these numbers?

Meaning of Decimal Numbers

Let us first consider the meaning of a familiar number —2,345. This is based on the conventional decimal system, which says that each number represents some power of 10. You may not be aware of it, but you mentally perform the following calculation when you see the number 2,345: you say that the 2 means 2000, that the 3 means 300, the 4 means 40, and the 5 means 5. Then you add these to get

2000 plus 300 plus 40 plus 5, or 2,345.

The important point here is that powers of 10 are involved. The above was derived from that fact that 1000 equals 10^3, 100 equals 10^2, 10 equals 10^1, and 1 equals 10^0. Thus the number 2,345 was derived from

$2(10)^3$ plus $3(10^2)$ plus $4(10)^1$ plus $5(10)^0$ equals 2,345

Meaning of Binary Numbers

In the decimal system, each "mark" is multiplied by a power of 10—that is, 10^0, 10^1, 10^2, 10^3 . . . . . which mean 1, 10, 100, 1000, etc.

In the binary system, powers of two are used—that is, 2^0, 2^1, 2^2, 2^3, 2^4, 2^5, 2^6, etc. Of course these mean simply 1, 2, 4, 8, 16, 32, 64, etc.

Let us consider the binary number 101101, and find its equivalent decimal number. This is simple. We do exactly what we did for the decimal number, using the numbers 1, 2, 4, 8, 16, 32, . . instead of 10, 100, 1000 . . . .

First write the number somewhat spread out with a plus sign between each mark:

$$1 + 0 + 1 + 1 + 0 + 1$$

Starting at the right, multiply the first mark (1) by 1; the second mark (0) by 2, the third mark (1) by 4 and so on as shown:

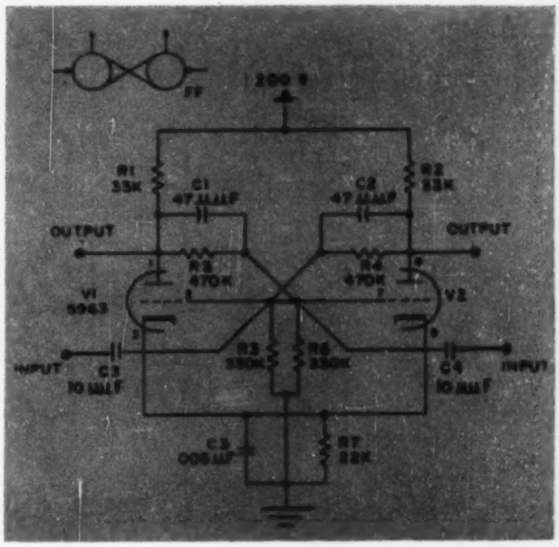

Fig. 2. Flip-flop, or counting, circuit. This circuit will count pulses at a rate of up to 100,000 pulses per second (that is, it will change equilibrium state at this rate), using negative input trigger pulses of 75 volts. (Photo courtesy EECO Production Company.)

$$1(32) + 0(16) + 1(8) + 1(4) + 0(2) + 1(1)$$

If we perform the multiplications indicated, remembering that 0 multiplied by anything is always 0, and add the result we get:

$$101101 = 32 + 8 + 4 + 1 = 45$$

Thus 45 is the decimal-number equivalent of the binary number 101101.

A table for some small numbers in our decimal number system and their equivalent binary numbers is given in Table 1. If we go through the operation indicated above, we find that we always obtain the equivalent decimal number indicated. For example, 111 means:

$$1(4) + 1(2) + 1(1) = 7$$

which is the decimal number given for 111 in the table.

Now let us consider how easy it is to do arithmetic with this system.

Adding Binary Numbers

To add binary numbers, we need to remember only two rules:

Rule 1: 1 plus 1 is 0, carry 1 to the next column.
Rule 2: 1 plus 0 is 1, which is obvious.

To verify this let us add two small numbers, say 11 (which is decimal number 3) and 01 (which is decimal number 1). Performing the addition according to the rules:

11
01
———
0, carry 1 to the next column

11
01
1 (carried)
———
00
carry 1 to the next column

The result is then 100. This, according to Table 1 is decimal number 4, which we know is correct.

Multiplying Binary Numbers

Multiplication is even simpler and requires that we remember only:

Rule 1: 1 × 1 is 1

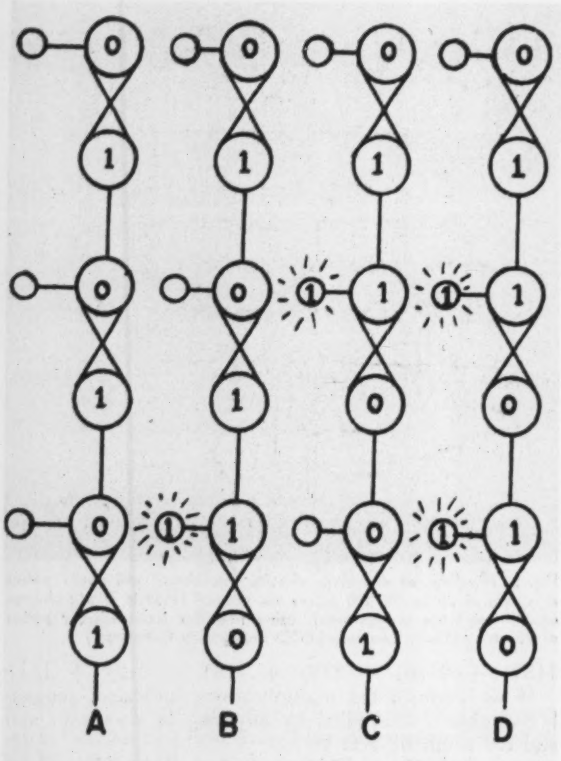

Fig. 3. Schematic of three flip-flops in series, with glow tubes in the plate circuit of each V2 section. A represents initial condition; B represents condition after one pulse; C represents condition after two pulses; D represents condition after three pulses.

Rule 2: 1 × 0 is 0

Let us multiply the numbers 11 (or decimal number 3) and 01 (decimal number 1). We should get 3 because 3 × 1 is three.

$$\begin{array}{r} 11 \\ \times\ 01 \\ \hline 11 \\ +\ 00 \\ \hline 11 \end{array}$$

11, which is 3.

These two rules replace all of the multiplication tables shoved down our throats in elementary grades; we don't have to remember 7 × 8 is 56, 7 × 4 is 28, and 9 × 7 is 63. Someday we might junk the whole decimal system and start our children in binary arithmetic forevermore, but this is a bit optimistic.

Binary Electronics

However, the electronics men have had to do just this because it is simple and inexpensive to count electronically in binary numbers—that is, using what is called a 1 state (or true state) and a 0 state (or false state.)

We can see how this is applied by considering a simple application. In Fig. 1 we see a set of SPDT switches: by convention we will call the up position "0" and the down position "1." Reading the switches from top down, and letting the top switch represent the leftmost number, the switches designate the binary number 001. If we change the position of the top switch as in Fig. 1, B, we arrive at the binary number 101.

Each switch configuration represents one and only one binary number. This is convenience itself. Notice that the switches have two conditions or "states," which we normally call the "on state" and the "off state." In binary terminology, we simply change the terminology to 1 and 0, and we see that the state of things is now described by a number instead of a lengthy word description such as: "The top switch is up, the bottom switch down, and the middle switch up." The single number represents the entire situation.

We can extend this thinking to a vacuum tube. If the tube is conducting, we can say the tube is "on" or in the "1" state. If it is off and not conducting, we can say it is in the "0" state. So we have a way of numerically stating whether a tube is conducting or not.

How could a tube indicate it is conducting? This can be done simply by putting a glow tube in the plate circuit of the tube. If the tube is conducting, the light is on and indicates that 1 state. If it is not conducting, the light is out and indicates the 0 state. Light on means 1, light off is 0. So here we have a way of finding whether a tube is conducting or not. More than that, we have a method available now to count pulses in a circuit and to determine the number of pulses by looking at a few glowing lights. This is done with a two-state circuit called a *flip-flop*, which is used extensively in binary numbers.

The Flip-flop Circuit

Fig. 2 is the schematic circuit of a practical flip-flop. The plate of each tube is connected to the grid of the other through a resistor in parallel with a capacitor. With the circuitry shown, only one tube conducts at a time. The voltage on the plate of the conducting tube is lower than that on the plate of the nonconducting tube. If a negative pulse is applied to the grids of both tubes, the conducting tube starts to cut off. Its rising plate voltage, connected to grid of the nonconducting tube, starts to make the nonconducting tube conduct. This in turn causes a falling plate voltage to be applied to the grid of the formerly conducting tube, cutting it off still further. This regenerative action causes the two tubes to reverse their states in a few microseconds—that is, the nonconducting tube becomes conducting; the conducting tube becomes nonconducting. Another negative pulse will reverse the situation. Another negative pulse will again reverse the situation. The circuit "flips" and "flops," back and forth, with each negative pulse.

Simultaneously with the change from nonconducting state to conducting, a negative step is generated at the plate load resistor of the tube changing state. This is the output of the tube.

What have we got? A circuit in which only one tube conducts at a time. Each negative pulse or step causes the conducting tube to stop conducting and the nonconducting tube to start conducting. *Every second pulse causes any one tube to conduct.* Suppose we call V1 the "zero" tube, and V2 the "1" tube—that is, when V1 is conducting the circuit is in "zero state," and when V2 conducts it is in "1 state." This is analogous to the switches discussed previously. Let us put a glow lamp in the plate circuit of the V2 tube: when it conducts the light glows. Therefore, when the circuit is in 1 state, the light indicates this state. When it is in 0 state the light is out. On, then, means 1 and off means 0.

Now let us hook a series of these flip-flop circuits in series and see what happens. Fig. 3 is a block-diagram of three flip-flops in series, with glow tubes in V2 plate circuit of each.

At the start, assume all of the V1 tubes in each circuit are conducting. Therefore, all of the lights are out. The lights are in the V2 plate circuits. We can say the tubes represent the number 000 because a light off means 0.

Now insert a single pulse; the first flip-flop circuit changes state and the light for this circuit glows. We now say we have the binary number 001; according to Table 1 this is decimal number 1 also. This means one pulse has entered the system. Now insert a second pulse. The first counter reverses 1 and the light goes out. But since the counters are cascaded, the negative pulse of V1 when it starts conducting affects the first tube of the second counter. The second counter reverses state, causing V2 in the second circuit to conduct. Now the light in the second circuit is on and we have first circuit light off or zero. This is the number 010 in binary, which according to Table 1 is decimal number 2. Two pulses have entered the system.

Insert a third pulse. The first counter reverses and its light comes on; so we have the binary number 011. This is decimal number 3. The procedure continues until all the lights go on and then the next pulse starts the cycle over again with binary number 000. We have available a method of counting pulses (negative voltage steps), but the counting is indicated in binary code.

Computing Machines

We have here the arithmetic element of most computing machines. These machines work in this binary code or numbering system, and this will account for the extraordinary rates at which they add or multiply.

Let us examine how we might add two numbers in this electron-tube circuit. Let the numbers be 2 and 3. First of all we might feed in 2 pulses to give the binary number 010—that is, only the second circuit light is on, the other two lights are off. Then we insert or add the 3 pulses we wish to add to the 2. The counters will change state and finally generate the binary number 101, which is decimal number 5. The pulses can be fed in at a rate of 100,000 per second, the fastest counting rate of this circuit, and the addition will then take place in little more than 5/100,000th of a second. Circuitry exists to count in excess of a million counts per second, increasing this speed by a factor of ten.

Diode Matrices

Another application is in connection with diode matrices. These are devices which activate a single line (or lead) at a time out of an entire group of leads. They also find application in computers and in automation or process-controlling circuits now coming into use.

The matrix is made of horizontal and vertical leads interconnected with diodes which have a relatively low forward-resistance and an extremely high backward-resistance. Let us examine the matrix shown in Fig. 4. Two flip-flops are used, and there are four vertical and four horizontal leads. When the flip-flop is in the zero state, the zero tube is conducting and the 1-state tube is nonconducting. The plate voltage in the 1-state tube is the supply voltage. We arrange for this voltage to exceed the bus-line voltage at the top of the matrix. The diode will not conduct if it "points into" a higher voltage than is driving it. This diode is said to be *back biased*, meaning the back voltage exceeds the forward voltage. If we reverse the state of the flip-flop, the plate voltage on the 1-state drops when it conducts and the bus supply voltage now exceeds the back voltage of the diode. The diode now conducts.

Let us start out with the flip-flops arranged so that it is in the state 00, meaning the 0 states of each tube are conducting. We find the diodes pointing into the second and fourth horizontal leads are all back biased; they are unable to conduct. The diodes connected or pointing into horizontal lines 1 and 3 are not back biased and are therefore conducting.

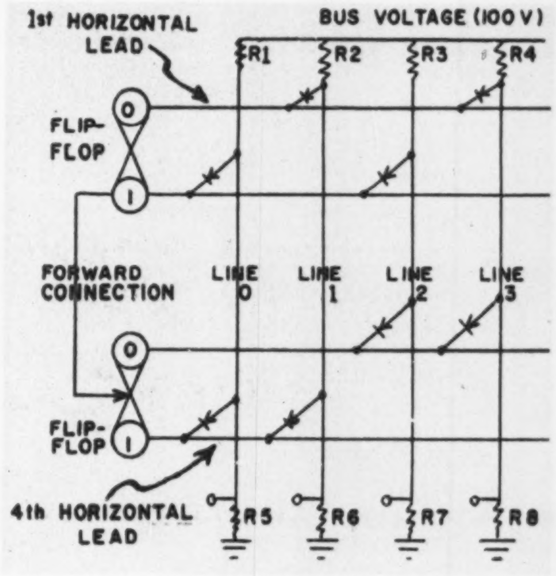

Fig. 4. Diode matrix controlled by flip-flops.

If we examine the vertical leads we see the ones marked 1, 2, and 3 are all conducting current (effectively to ground), shorting out the resistor at the bottom. However, line 0 is not grounded through a conducting diode; therefore, the bus supply voltage appears across R5 when the flip-flops are in the state 00.

Now let us insert a pulse into the counter and advance the topmost counter to 1, giving the counter state 01. Now we find that horizontal leads 2 and 3 are not back biased. Going down the vertical lines again we find that the vertical marked 1 is ungrounded. Therefore, when the counters are in the state representing 01 (which is decimal number 1), vertical line 1 is the only line not grounded and therefore the only line where the voltage appears at the bottom resistor (R6). Change the state of the counters to 10 (decimal number 2) and, by the same reasoning, we will find line 2 the only ungrounded line. So we see that we can distribute the bus supply voltage to any of the four lines, one at a time, by setting up a certain binary number in the flip-flops at the end of the horizontal line. This can be extended to any number of flip-flops. For example, with eight flip-flops and the proper diode connections, we can switch the bus supply voltage to any of 256 lines, simply by inserting pulses into the counters and letting them count in binary. While they are counting, the associated diode matrix is activating corresponding lines. This is the principle of *electronic multiplexing* or *time sharing of lines*, which finds increasing importance in communications and computational work.

In summary, we note that all of this is based on a binary number system, and the electronics are actually physical manifestations of binary arithmetic. The circuitry provides means for counting and performing arithmetic operations. Switching operations can be performed when associated diode matrices are used. The latter can be used also to perform logical operations, such as to cause voltage to appear on a certain line when a certain binary input appears on the counters. Applications engineers are finding increasing use for these simple circuits; in this age of automation they will be the foundation on which many control circuits will be built.

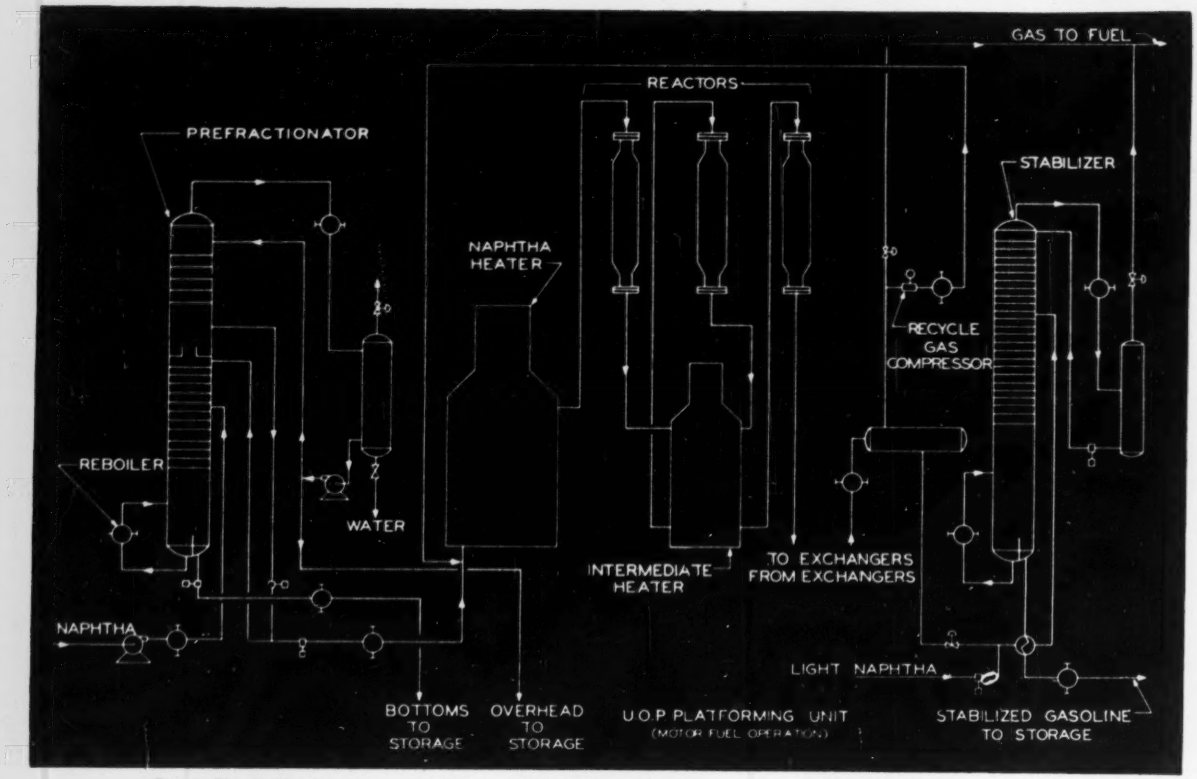
GAS TO FUEL
REACTORS
PREFRACTIONATOR
STABILIZER
NAPHTHA HEATER
RECYCLE GAS COMPRESSOR
REBOILER
WATER
INTERMEDIATE HEATER
TO EXCHANGERS
FROM EXCHANGERS
NAPHTHA
LIGHT NAPHTHA
BOTTOMS TO STORAGE
OVERHEAD TO STORAGE
U.O.P. PLATFORMING UNIT
(MOTOR FUEL OPERATION)
STABILIZED GASOLINE TO STORAGE

Fig. 1. The Platforming process of Universal Oil Products Co. (Photo courtesy Universal Oil Products Co.)

First

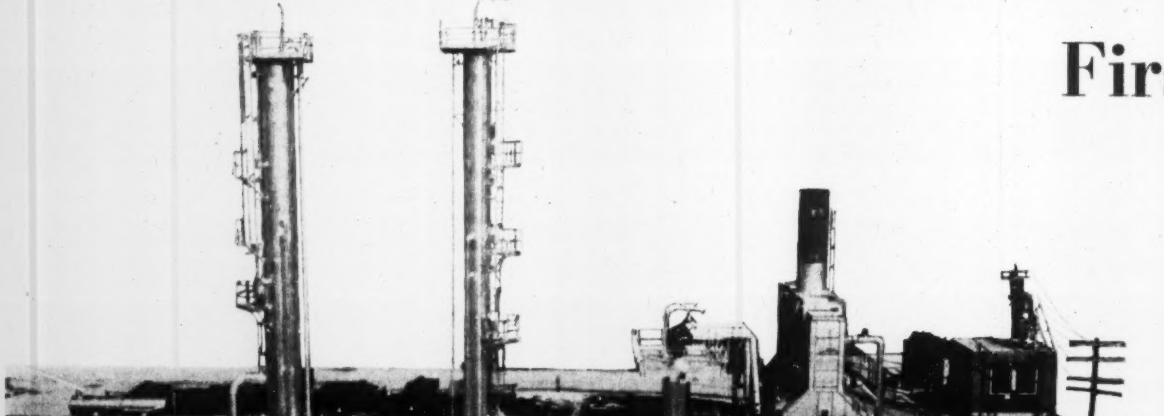

Fig. 2. Over-all view of the UOP Platforming unit at the Rock Island Refining Corporation, Indianapolis, Ind. This is the first refinery unit in the United States to be entirely controlled with electronic instruments. From left to right are splitter and stabilizer columns, reactors, and reactor charge heater. (Photo courtesy Universal Oil Products Company.)

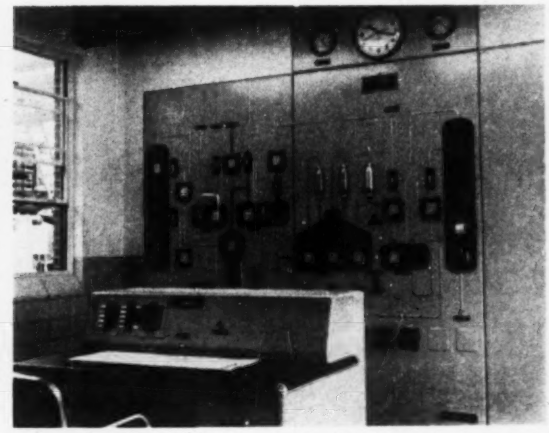

Fig. 3. Central control station for the Platformer, showing graphic panel. (Photo courtesy The Swartwout Company.)

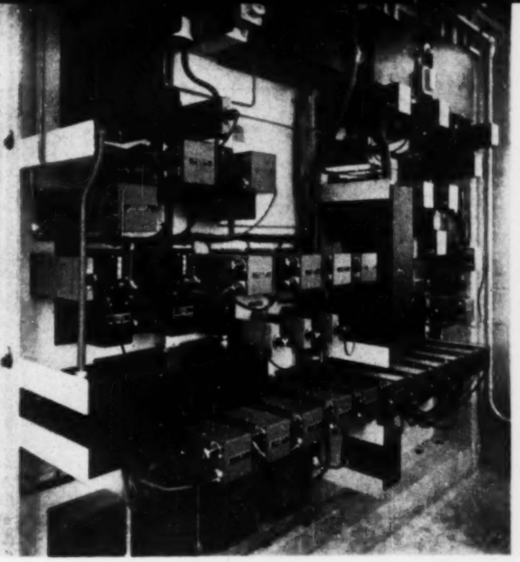

Fig. 4. Rear view of graphic panel. (Photo courtesy Universal Oil Products Company.)

LEON STEWART
Rock Island Refining Corporation

The pioneer user of an electronic process control system reports on the success achieved in controlling a UOP Platformer. Basic advantage turns out to be the better control resulting from the higher derivative rate made possible by the greater sensitivity and response speed of the electronic control system.

Electronically Controlled Refinery

IN starting up a new 2,400-barrel-per-day UOP Platforming unit recently, Rock Island Refining Corporation at Indianapolis, Ind., again gained the distinction of pioneering a new step in the field of process control. In August of 1949 the company became the first refinery in the world to put into operation a complete refinery controlled by a graphic panel. The new Platformer is the first complete refinery unit in the United States to be controlled by electronic instruments.

The Platformer

Our Platformer went on stream July 6, 1954. The Platformer, a catalytic reforming process, increases the octane rating of our gasoline.

Our UOP Platformer (Fig. 1) consists of 4 sections—a prefractionator, a heater-reactor section, a separator-compressor section, and a stabilizer section. The prefractionator is a fractionating column used to prepare our feed stock for the reaction. The heater-reactor section consists of 3 heaters and 3 reactors. The platinum-bearing catalyst is in the fixed-bed reactors. The reformate is separated from the excess hydrogen and other gases in the separator. Since catalytic reforming includes a dehydrogenation process the net make hydrogen is vented in this section. The hydrogen to be recycled is run through the compressor to rejoin the feed stock entering the first heater. The reformate is stabilized in the final column.

Control Variables

Optimum operation of the unit depends on proper control of four process variables—temperature, space velocity, pressure, and hydrogen recycle rate. An increase in temperature at the reactor results in a higher octane output. As the catalyst ages, increased temperature is required to obtain the same octane output. A control system is required that can increase the temperature a few degrees at a time, and also respond accurately and rapidly to slight increases.

Choice of Controller

Before instrumenting our Platformer we compared electronic and pneumatic controllers on the basis of operation, reliability, ease of maintenance and installation, and economy. To test the electronic controllers several units were installed on our catalytic cracker. An electronic temperature recording and controlling system, installed in parallel with a pneumatic system, performed better than the pneumatic.

One factor affecting the reliability of pneumatic control is freezing air lines, especially when the air drier does not function properly. Also, the Instrument and Electrical Departments decided that they could run conduit and install electronic controllers as cheaply and easily as installing copper tubing and pneumatic controllers. Our

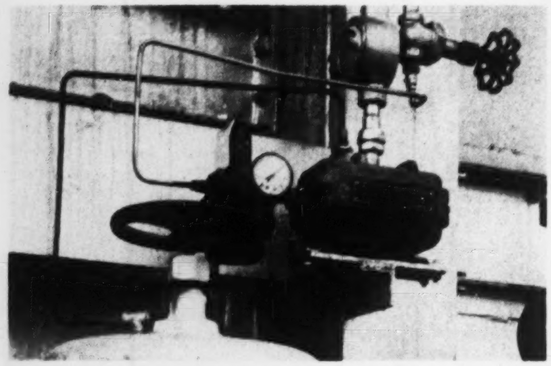

Fig. 5. Swartwout explosion-proofed electro-pneumatic transducer that converts the electronic impulse originating at the graphic control panel into a pneumatic signal for positioning the valve. Heater strips assure all-weather operation. (Photo courtesy Universal Oil Products Company.)

Instrument Department felt that with specific information about the circuits they could maintain the electronic controllers.

After discussing the feasibility of employing electronic equipment on the Platformer with Universal Oil Products Company, which designed, engineered and licensed the processing unit, we decided that the electronic controllers promised better control, reliable operation, cheaper installation, and easier maintenance. We therefore specified them on our Platformer, and chose Autronic instruments manufactured by The Swartwout Company.

Installation and Start-up

While we were constructing the Platformer no problems arose that could be considered unique to electronic control. The conduit to the units installed in the field was mounted on the process piping racks rather than on expensive, additional tubing racks. The panelboard was built and wired by Panellit, and we were pleased with the simplicity of the back of the board (Fig. 4).

We started to heat the recycle hydrogen on July 5; the next day at 9:22 AM we cut in the naphtha charge. By 10:00 AM the entire process was on automatic and all variables were stabilized. The Platformer has been operating continuously since that time. The smoothness of this start-up was due to our giving the control system a complete check-out before start-up.

Performance

Subsequent performance (now five months) has exceeded our expectations about the job that electronic controllers could do. The reason for the superiority is that the combination of high *speed of response* plus *high sensitivity* allows proper corrective action to be taken as soon as the process variable starts to deviate from the control point—even before it is visible on the chart. This lack of a dead zone is most apparent in our temperature control systems. Present potentiometric instruments require mechanical motion, operation of a pilot valve, or mechanical rebalancing of a bridge circuit before rate response can be added to the control loop. This "part-time" operation makes it impossible to take full advantage of rate response. The all-electronic control system is more sensitive to small changes in the variable, both slow and fast, and can compensate for the slightest input changes. This permits higher rate-response settings to be used. Our temperature systems are extremely stable due to the greatly increased rate-response settings we are using.

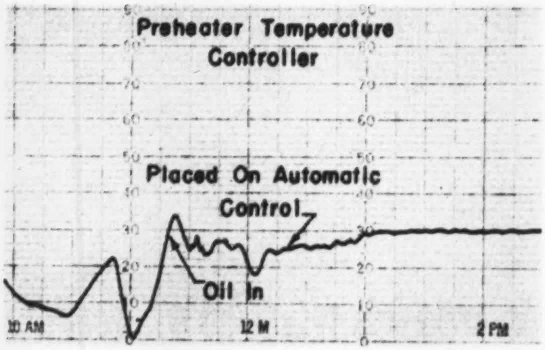

Fig. 6. Temperature control of the heater.

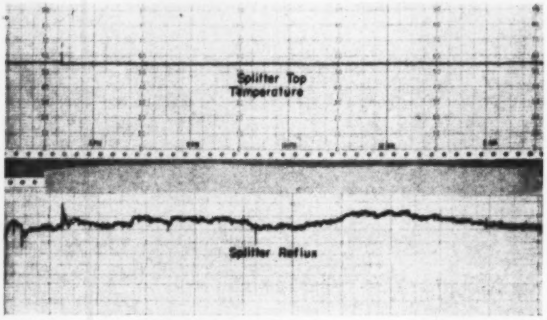

Fig. 7. Temperature control of the fractionator.

The installation at Rock Island has shown the value of this feature. The derivative settings have been adjusted to rates that were never thought practical before on similar applications because of the distorted picture that was obtained of the rate of change in the process when mechanical and pneumatic techniques were used. By being able to use greater derivative action, and by having greater sensitivity in the controller, it has been possible to correct even small temperature changes *before* they became noticeable on the recorder.

Maintenance

Our Platformer has been in operation only five months so we do not have enough maintenance experience to justify our assumption that electronic instrumentation should be as easy to maintain as a standard pneumatic system. Maintenance to the present time has been low; calibration and routine checking of the instrument leads us to believe that maintenance costs will be lower.

Conclusions

The equipment in use at Rock Island has proved superior to pneumatic control for these reasons: (1) They are more reliable in cold climates. (2) They eliminate the need for tubing and racks with their high costs and maintenance problems. (3) They can give better control due to their greater sensitivity, or lack of dead band. (4) They permit greater use of the derivative control function because they lack the tendency to distort the measurement of the *rate* when the process variables change.

It has always been the policy of Rock Island Refining Corporation to be as progressive as can be justified within the limits of safety, financial return on investment, and personnel acceptance. We installed and are still operating the first graphic panel using stack-type pneumatic controllers; these are now in general use throughout the refining and chemical industries. We believe that electronic control systems are an equally big step forward, and that on the basis of our experience this type will have widespread use in the petroleum refining industry.

Automatic presses use automatic feed and safety limit switches. The present status and trends in design are presented.

T. W. BANNON

Clearing Machine Corp.

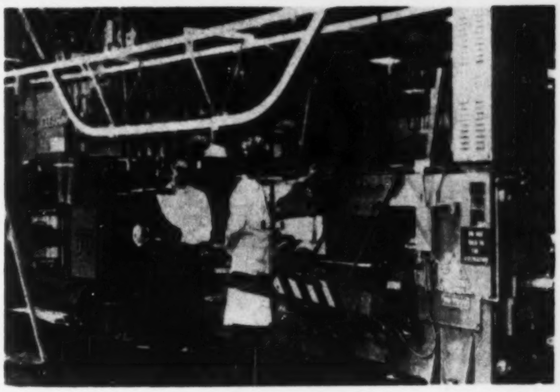

Fig. 1. The double-end press that punches on both ends of the stroke.

AUTOMATIC PRESSES

Automation is not new in presses. Automation principles were first applied to the presses themselves, and later to the mechanisms for feeding and unloading them.

It started with use of combination tools or dies on single-action presses so that more than one operation could be performed on a single workpiece. After that came double- and triple-action presses as well as multiple-station presses. Still later, so called *transfer feed presses* were developed. In this type of press a number of operations are performed in a straight line; transfer presses have limited possibilities for combining blanking, drawing, and trimming operations. Still later, cycling times on presses were stepped up, and recently underdrive presses have been put in to use to ease material flow and aid in maintenance.

Among the great strides made in feeding and unloading of the larger presses were the use of electronic devices to control the feeding in high-speed blanking and drawing presses. Magnetic feeds and transfers also deserve recognition.

Present Status

Examples of recent automatic presses reveal the present status of press builders in their attempts to keep abreast of automation demands. Clearing engineers recently designed and built a new kind of hydraulic press for the production of cartridge cases. A press which has to draw a shell to a final length of 24 inches requires an unusually long stroke. The equally long return stroke necessarily slows down the return time. One way of reducing lost time is to produce at both ends of the stroke, eliminating lost motion from operating time. The Clearing Double End Press (Fig. 1) does this and has a number of other automation features too. Each press has an automatic feed (Fig. 2) especially adapted to its function. Safety limit switches on the presses make certain that the case is properly positioned before the press will operate.

Three completely automatic shell-forging units recently built by Clearing each consist of three automated presses and an automatic descaler. These presses (Fig. 3) forge a 75-, 90-, or 105-mm. shell forging without a human hand touching the piece part. The machines run continuously and have a capacity of six shell forgings a minute. The presses are completely automatic, even to the point where the scale is cleaned from the dies and the lubrication furnished to the presses between each cycle.

Trends

What does the future hold for press automation? Trends in press design will be to complete stampings in one or two presses. Feeding and unloading components will become standard equipment as well as electronic controls for actuating the press. The entire press line will be operated from one master control panel. Cycling rates will be stepped up even higher. New methods of simplifying and combining operations will undoubtedly be developed. Automation will eventually reach the job-shop level, and users and builders alike will have to supply some not-too-easy answers.

Presented at the 18th Annual Machine Tool Electrification Forum, sponsored by the Westinghouse Electric Corporation, Buffalo, New York, April 6 & 7, 1954.

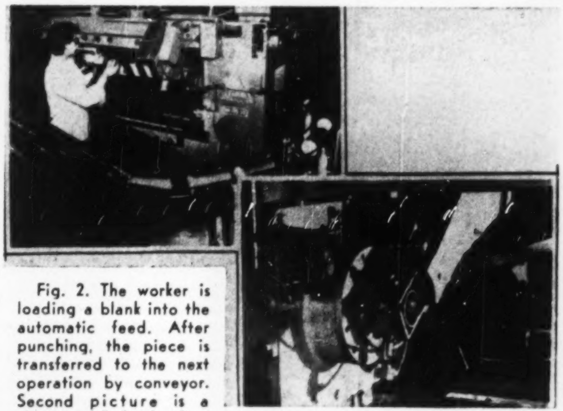

Fig. 2. The worker is loading a blank into the automatic feed. After punching, the piece is transferred to the next operation by conveyor. Second picture is a close-up of the loading mechanism.

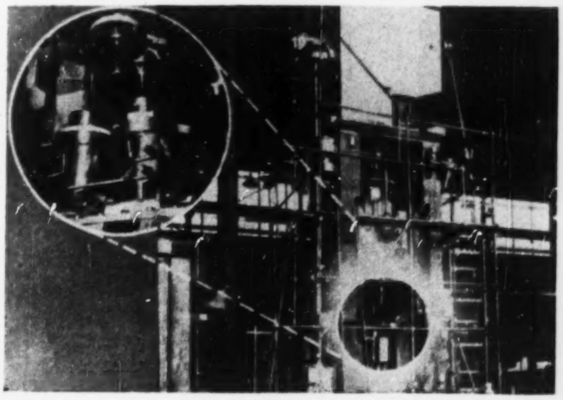

Fig. 3. An automatic shell-forging unit, showing close-up of tools in inset.

The Automatic Factory—

Analysis of the degree of automaticity attained by typical manufacturing industries of various sizes illustrates (1) the appalling disparity between contemporary automaticity and the co-called "automatic factory," (2) the severity of the cost obstacle for smaller firms, and (3) the fact that the specific context of each company is the framework within which automaticity must manifest itself.

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V. Contemporary Automaticity

PREVIOUS discussions reviewed the major obstacles in the way of the automatic factory. In the following discussion, several case studies will be presented in an effort to learn what steps some companies have taken to automatize their manufacturing operations. More specifically, the value of each study will be increased if it is considered in relation to four questions: (1) What has this firm accomplished in terms of increased automaticity? (2) How was the accomplishment made? (3) In what functions is this firm farthest from complete automaticity? and (4) Why has progress been slow on these least automatic functions? The first two cases deal with automobile companies; the last two are about Project Tinkertoy and Atwood Vacuum Machine Company (a job shop producing in small lots).

The Automobile Industry

The great strides taken in recent years by members of the automobile industry in connection with automatic production may be characterized as being primarily advances in the art of handling materials through machining operations. Much less has been accomplished in finishing or assembly. This difference cannot be traced to a lack of interest—the task of automatizing assembly operations is simply much more complex than is the job of automatizing the handling of materials. Automatic assembly is presently limited to rather small sub-assembly operations. One company, for example, has been able to introduce automaticity into the assembly of spark plugs. The assembly of radiator pressure caps has also recently been made automatic. But these, of course, are only "sub-assemblies." Compared to a complete automobile, the difference is of tremendous proportions.

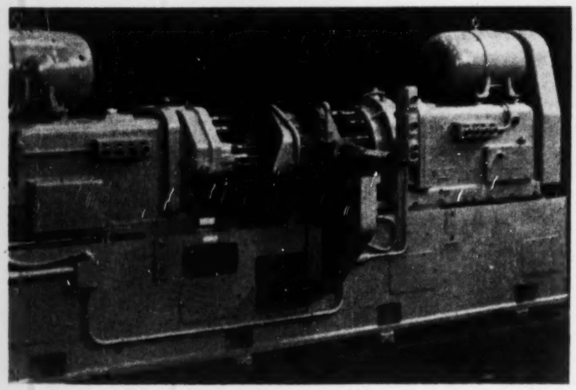

Fig. 5-1. Drilling machine with single station and combination tooling.

Important reasons for the ability of the automobile industry to realize gains in automatizing its materials handling functions derive from the design and construction of transfer machinery.

One of the leading producers of transfer machinery is The Cross Company of Detroit. Ralph E. Cross, Executive Vice President of the company, has sketched the development of transfer machines in an article* entitled "Trends in Automation." His review indicates a logical, step-by-step development from single-station machine tools using multiple tooling to the present form of transfer equipment involving multiple tooling in multiple stations laid out in a straight line.

Fig. 5-1 is an example of a single machine using combination tooling. It is a two-way multiple-spindle drilling machine which completes 32 operations on a rear axle housing. The development of single-station machines continued until it became impractical to add more tools because (1) it became difficult to get workpieces in and out

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* *Instruments and Automation*, Vol. 27, page 768, May, 1954.

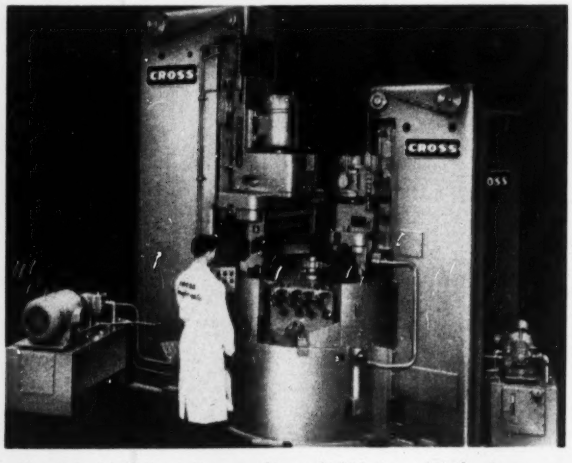

Fig. 5-2. Multiple-station machine of dial type. Work pieces are attached to index table that is rotated from station to station; multiple operations are performed at each station.

A Critical Examination

Prepared for General Georges F. Doriot in partial fulfillment of the requirements of the manufacturing course at the Harvard Graduate School of Business Administration.

of their fixtures and (2) the presence of many heads turned the job of changing tools into a major operation.

These conditions fostered the development of the multiple-station machine; Fig. 5-2 illustrates the dial type and Fig. 5-3 the trunnion type. In these machines the workpieces are placed in fixtures which are attached to index tables or trunnions. The parts are indexed from station to station; multiple operations are performed in each station. These machines are subject to a definite limitation. This is the diameter of the table or the trunnion; the larger the table the greater the indexing error. Because the size of the table is limited, the number of stations is limited. Out of this limitation grew the modern transfer machine.

Transfer machines are now of two general types—pallet and plain. In the pallet type (Fig. 5-4) the parts are first clamped in fixtures and then transferred from station to station where the machining occurs. In the plain type (Fig. 5-5) the parts are located and clamped separately at each station. At the beginning the parts are placed in the loading station and then are transferred from station to station until they reach the end of the line, where they are ejected.

Fig. 5-6 represents an advanced example of transfer equipment. It is a "machine" for the machining of V-8 cylinder blocks. It is 350 feet long, performs 555 operations, automatically handles the part in 7 different positions, and has a capacity of 100 parts per hour. At any one time, a total of 104 pieces are in process. The entire line is controlled by one operator.

Two features of the machine are of particular interest: (1) automatic tool programming and (2) automatic banking. The latter is a method of eliminating manual handling of parts at the time of tool changes. The automatic tool programming is designed to cope with the problem of down time due for tool changes. The problem of tool changing is presently the limiting factor insofar as the number of operations that can be combined into one transfer machine is concerned; the present chief problem in machine-tool automation is down time because of tool changing. As the number of tools in the machine increases, so also does the time required to change those tools. One way of controlling down time is through the use of tool programming for each individual tool.

Fig. 5-7 shows a tool programming device called the "Toolometer." This mechanical memory device totalizes the number of operations that a tool performs while working, then shuts down the machine for changeover according to a predetermined schedule. The schedule is determined by estimating the life of the tool and by using a technique of "Sectioned Automation."

In "sectionized automation" the machine line is divided into sections. This permits the shutting down of some operations without interrupting the operation of other sections, which continue to bank up parts while following sections are fed from a previously accumulated bank.

Attention will now be directed to the Brown Co. (disguised name), a large automobile manufacturer.

The Brown Company

The achievement of this company in the field of automatic production is characteristic of the developments experienced

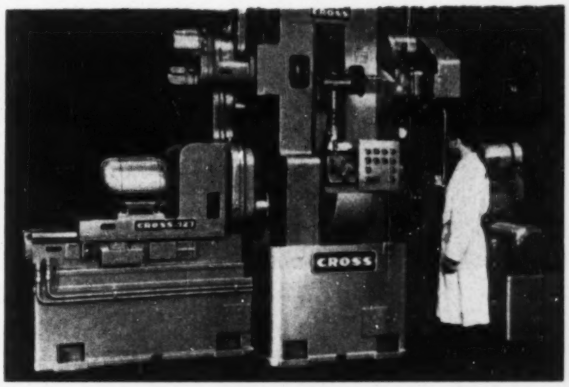

Fig. 5-3. Multiple-station machine of trunnion type. Work pieces are attached to movable trunnion.

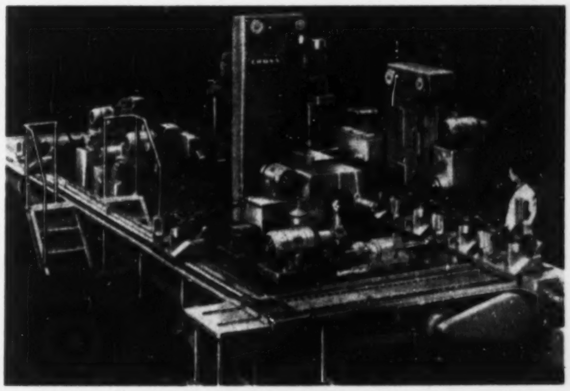

Fig. 5-4. Pallet-type transfer machine in which parts are clamped to a fixture, or pallet, attached to conveyor.

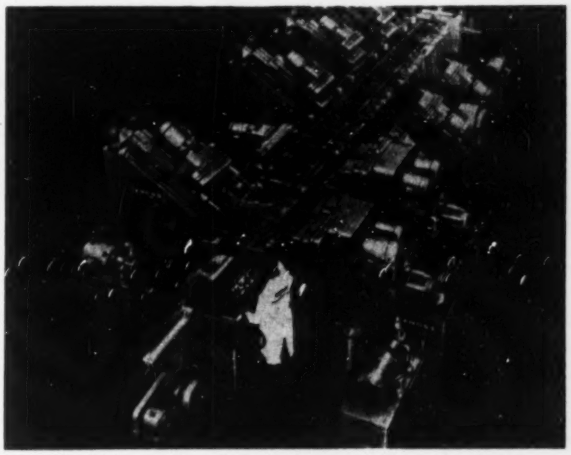

Fig. 5-5. Plain-type transfer machine in which part itself is transferred from station to station, being clamped separately in each station.

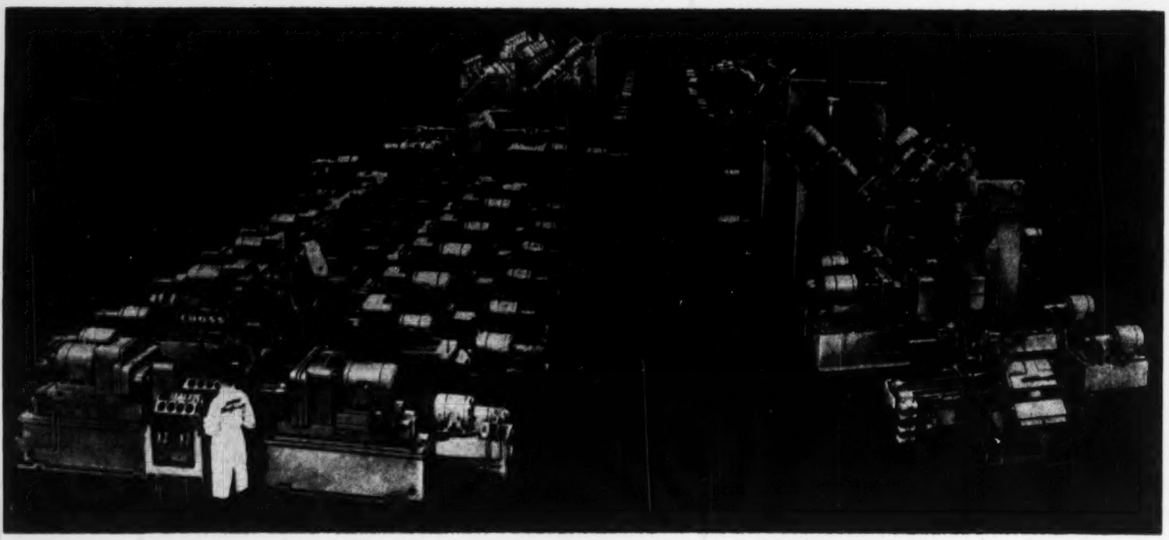

Fig. 5-6. Late model 350-foot machine for machining V-8 cylinder blocks using "sectionized automation."

by leading companies in the automobile industry, and lies primarily in the area of materials handling. Much use has been made of transfer machinery. Several years ago, the management of Brown decided that four goals could be realized if a new method of automatically handling parts between manufacturing operations could be developed—(1) to reduce production costs, (2) to improve product quality, (3) to increase the efficiency of machine tools, and (4) to insure against an inadequate labor supply. Work was begun to develop new methods of transferring parts between machines.

Executives of the Brown Company decided that the best way to approach their problem was to establish a separate department which would be charged with the responsibility for discovering and capitalizing on opportunities for automatizing the materials handling function. This approach has been continued and expanded until, presently, "groups in every division of our Company . . . are assigned the problem of automation for the parts manufactured within their division."

Once the new department was established, the approach taken was to work with standard and existing machines. These were rearranged and tied together with mechanical devices, thus resulting in the beginning of the "Inline Machine." As experience accumulated, emphasis was shifted from work with standard and existing equipment to entirely new machinery and equipment "which have been designed with automation in mind." Essentially, the attack followed now is on a part-by-part basis. That is, a part is studied to determine whether "automation possibilities" exist. The specifics of this company's approach can be appreciated by listening to their story in their own words:

"We ordinarily give one automation engineer responsibility for the work on a complete automotive part. As the detailed plant layout is developed, the automation man must be readily available for consultation so that arrangements can be made for the installation of the simplest possible transfer mechanism. At this point in the process, many interested groups from production and higher management view the developments to see the overall plan.

"It is the time for quick calculations and simple sketches to help determine in a preliminary way the extent of automation which is justified by the economic factors. We quite often find that the right type of automation equipment costs very little more than standard equipment which could be considered a minimum requirement. We can see here the value of close coordination on the program at this point and it must be strongly emphasized.

"The part to be produced must be carefully studied for adaptability to automation. Preliminary manpower estimates must be considered. We find that one operator can load and unload several or more machines. He may be required for reasons other than loading and unloading; such as assembly, manual control or observation; and automation may not be advisable.

"Once we decide on the plant layout to be used, copies are made and the automation engineer starts his detailed study for determination of the complete program. An overall preliminary automation layout is made. It shows all of the elements required. In some cases, models and three-dimensional drawings are made to be certain of some of the details and to make proper presentation to management for approval.

"This preliminary automation layout is then analyzed for the estimated installed cost.

"Our Industrial Engineering Department analyzes the manpower requirements by comparing the Automation Layout with the standard layout using the minimum equipment. When these are completed, we then have the cost figures which enable us to make a proper decision as to the extent of automation which may be required. This data is summarized and presented to Management for approval.

"When and if the program is approved, the really important work begins. The automation engineer must now coordinate all phases of design. He must see that the initial or preliminary plant layouts which were developed are revised wherever necessary so that the automation equipment is allowed adequate space. He must advise the Processing Department to revise their operation sheets where necessary to include the automation equipment. He must also consult the machine-tool designer so that the loading and unloading stations are properly prepared for automation for working height, position, clearance, etc.

"At this point we are ready to proceed with the procurement of equipment.

"Inasmuch as automation equipment is a key item in a production process, we feel that the method of placing all of the responsibility with one party, the Automation Engineer, is a much better one if it can possibly be utilized. Even assuming that this method is utilized, the automation program is incomplete until the job is actually operating successfully. For this reason, the Automation Engineer must continue to follow the program until the entire system is in operation. It is necessary to keep in close touch with field conditions to take care of minor changes which may be necessary as the various other items of production equipment are installed in their proper places."

What the Brown Company has accomplished, with respect to automatic production, revolves primarily around the materials handling function. The machining operations involved include milling, broaching, reaming, tapping, drilling, boring, spot facing, chamfering, and countersinking. The parts that have been "automated" range from cylinder blocks and heads to gas tanks, pistons, and ring gears; inspection has also been automatized in many cases. The production of automotive crankshafts provides an example: one part of the production process for this part involves the drilling of "six oil holes, six metering holes, six lightening holes, and inspection of the operation." Three transfer machines having eight stations each perform the drilling and inspection operations.

As is true of the industry generally, the Brown Company has realized considerably fewer results in the area of automatic assembly. One executive indicated that the "size of the part to be assembled is a limiting factor." He stated as another example of a limiting factor the fact that "sheet metal parts cannot be held to exact tolerances—they bend slightly after stamping, and have to be adjusted by hand."

There are other reasons why automatic assembly has had a slow development, aside from the sheer difficulty involved: style and design changes are major reasons. For items subject to substantial annual design changes, it is necessary to foresee a payout period of a year or less before investment is undertaken in automatic equipment.

It is important to note that the Brown company sells to a mass market and that it accordingly produces on a similar scale. Its financial resources are large and it thus possesses the ability to call on substantial engineering skill.

The Green Company

The Green Company is also a large manufacturer of automobiles. Its experience with automatic production parallels in many ways that of the Brown Company. Transfer machinery of the same general type is used. There has been a difference, however, in the methods followed by the two companies in installing their transfer equipment. In the case of Brown, their "automation department" has "shopped around" and purchased from several machine-tool builders the necessary equipment for a production line. Green Company, on the other hand, has generally followed the practice of relying on one tool builder to provide all the essential machinery for a particular production line.

The Green Company, like others in the industry, has also encountered its greatest difficulties in assembly operations. The approach of the company is to concentrate on the problem of the "simpler assemblies, where there is a lot of labor now engaged or where it is difficult for a man to do the assembly (e.g., picking up pins)." Jobs where "several operators are being used to do the same operation" offer "good tipoffs which might indicate that mechanization is feasible and would result in savings."

One executive of the Green Company has listed the factors which he thinks ought to be considered when approaching the job of mechanizing an assembly operation. His selection is illustrative of some of the current thinking by manufacturers on the problems of automatic production. The outline of his considerations is presented:

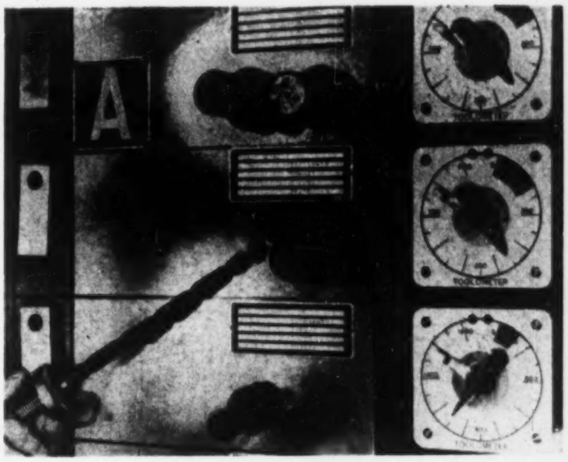

Fig. 5-7. "Toolometer" for individual tool programming.

1. Comparison between equipment cost and labor savings.
2. The effect of volume; present and potential
   Cost of equipment idleness
   Period of time to design and build equipment.
3. Product quality—(uniformity)
   Automatic sorting and inspection
4. Flexibility of equipment design
   Product design changes
   Obsolescence
   Continuous or seasonal products
5. Complexity of equipment
   Will an operator be replaced by a mechanic?
   Over mechanization—partially busy operators
   Cost of maintenance
   Cost of downtime due to non-uniform parts, jamming, or mechanical failures
   Safety
   Floor space
6. Equipment design from operator viewpoint
   Leg room
   Sitting-standing principle
   Stock supply and disposal provisions
   Avoid barriers
   Proper location of controls
   Correct motion pattern

Project Tinkertoy

"Project Tinkertoy" is the code name of a project involving the mechanized production of electronic sub-assemblies. It was begun in 1950 under the sponsorship of the Navy Bureau of Aeronautics and it was carried out by the National Bureau of Standards. During 1949 and 1950, study of the electronics industry indicated to the Navy that trouble would develop in connection with procuring needed electronic equipment in the event of a sudden mobilization period. It was concluded that in view of the quantities and varieties of electronic equipment needed, the costs of producing and maintaining such equipment would be formidable. Both the capacity of the industry and its ability to mobilize rapidly seemed inadequate. In an effort to correct this situation, the Navy turned to the National Bureau of Standards. The NBS had qualified itself for this new job by engaging in considerable work on electronic equipment prior to 1950. During World War II, extensive work with printed electronic circuits stemmed from the Bureau's work on proximity fuzes. And by the time it was asked by the Navy to undertake this new job,

"Although Tinkertoy is revolutionary ... it illustrates the major obstacles (to automation)"

the Bureau "had developed a modular design concept, tape resistors, special circuit-printing technique, and hand machines for printed circuits."

The efforts of the NBS and those of other companies who assisted on the project have resulted in a pilot plant producing, by highly mechanized methods, electronic subassemblies. The plant is now operated for the Navy, under contract, by the Kaiser Electronics Division of Willys Motor Company.

Proof that the production of electronic assemblies can be mechanized has had a major impact on the electronics industry. But the significance of Tinkertoy is even more widespread than this. In terms of automatic production, the accomplishment of Tinkertoy is definable primarily in the area of automatic assembly of discrete units. The Project also incorporates automatic inspection, via punched-card techniques, at every major operations point. However, the inspection process does not include automatic correcting means (i.e., feedback). When a certain number of rejects are registered, a warning sounds, and manual attention is directed to the cause.

The fundamental concept which has enabled mechanized assembly to occur in Tinkertoy is "redesign." This is a word often used—perhaps overly so at times—by writers on the automatic factory. In Tinkertoy, redesign has been applied not only to the product, but also to the process and to the production equipment. But most important, and the key to the success of Tinkertoy, is the design system developed for the products themselves; the printed circuit is the basic facilitating factor.

Although Tinkertoy truly is an accomplishment of revolutionary significance both for the electronics industry and for industry generally, its attainment also illustrates the necessity of meeting the major obstacles discussed previously. The production process at Tinkertoy is highly mechanized and it does involve automatic inspection, but it is not an automatic process in the sense of automatic feedback control. Thus the complexity of the process still exists as an obstacle to completely automatic operation.

The printed circuit itself was not achieved overnight. The NBS did extensive work on printed-circuit technique for a number of years, and actual development of the concept goes back more than 25 years.

The cost obstacle was also present in the Project. Although the equipment now used in Tinkertoy could probably be duplicated for about three quarters of a million dollars, the developmental costs of the project amounted to over $4.7 million. This burden was born by the government, but would have been a formidable burden for a private concern.

The problem of having to coordinate a number of separate concerns and separately located skills was also present. A number of firms in addition to the Bureau of Standards were called on to provide essential equipment and know-how. These included Kaiser Electronics Division of Willys Motor Co.; Doughnut Corp. of America; Communication Measurements Laboratory, Inc.; Sanders Associates, Inc.; the Davies Laboratories; and the Navy Post Graduate School.

Atwood Vacuum Machine Company

Atwood is a job shop primarily making pressed metal assemblies. The problems it encounters with respect to automatic production therefore differ considerably from those faced by "mass-producing" companies. Its accomplishments in the area of automation (mechanized materials handling) are unquestionably minor when compared to those of the automobile companies.

The executive vice president of the company believes that "because of a job shop's requirements for flexibility in production, further improvements probably will not be along traditional lines of constructing special-purpose machines for producing a more or less standardized product in large volume." He believes instead "that there is another road that can be traveled as far as the job shop is concerned and that is to link together relatively standard processes which are of a flexible nature in order to achieve greater economies in processing and handling." The experience of his company with mechanized materials handling has been focused in this latter direction.

Atwood's steps "to get ready for future steps that might be taken to mechanize or automatize our operations" were motivated by a desire to lower costs. Company executives felt the most opportune way to do this was to reduce direct labor. In an effort to effect economies in labor, the executives asked themselves "what essentially does labor do?" The answers they found were: "it moves material in and out of machines, between machines, from raw stock into production, and from finished parts into assembly and then into shipping." On the basis of this analysis, it became clear that mechanization of the materials handling function would yield substantial direct labor savings.

The desire to realize these savings had to be conditioned by an important essential circumstance: flexibility. The importance of this can be appreciated when it is noted that Atwood presently ships about 500 different assemblies per month. On the average, each of these assemblies involves four parts. Thus a total of 2000 different parts are processed through the plant monthly. Over a thousand different machine tools are used in the plant. These include presses, mills, drills, welding, grinding, heat treating, plating, and painting equipment.

Essentially, Atwood's change was from a functional departmental layout ("machines were grouped by type in departments") to a modified product line layout. In this latter way, it became more possible to utilize mechanical handling devices (such as chutes, conveyors, feed mechanisms, overhead cranes, and air rejection devices). Ten thousand planning hours and a new plant were required to carry out the program. The job of determining the job-shop production lines was carried out as follows:

1. Determine the number of production lines.
    - (a) "Make a card for each active manufactured part, and record the manufacturing operation sequence on this card."
    - (b) "Sort these parts cards by grouping like-operation sequences to determine the number of pro-

"... ability to coordinate for automaticity appears to rise in proportion with financial resources"

duction lines." Punched cards were used for this job and then a judgment was made of the number of lines needed by examining "the number of parts falling within a like-operation sequence group."

2. Determine the number of machines needed in each line.
   (a) "List the monthly experienced or anticipated volume of production for each part on the operation sequence card.
   (b) "Determine the average monthly production rate of a machine for each type of operation.
   (c) "Divide the total monthly volume of parts for each operation in each production line by the monthly machine production rate for that operation. The quotient obtained is the number of machines that is required for each operation in each production line."

The experience of the Atwood Company with automatic production illustrates the appalling disparity that exists between the level of automaticity presently existing in thousands of industrial plants and that which will constitute the so-called automatic factory. *The concept of feedback is absent in this firm's processes.* Automatic controls, as such, are used, of course, but anything similar to our automatic process is non-existent. Mechanized material handling constitutes the limits of this company's experience with automatic production.

Yet to minimize Atwood's achievement on the basis of a comparison with the automatic factory constitutes a judgment hardly valid when related to the problems of a job shop, such as Atwood. The products the company processes are numerous and they differ in many characteristics. In these circumstances, the chances of economically justifying special-purpose production equipment are slim indeed. Flexibility is the master and obeisance to its dictates is unavoidable.

Conclusions

The experience of several industrial organizations with automatic production has been examined. Major attention has been focused on the piece-part industries, as these are the ones furthest from a continuous-flow-type of production process. The point of view has been one of trying to determine what these organizations have accomplished in the area of automatic production, what problems were encountered, and how they were met. The following question now seems pertinent: What conclusions may be drawn from the experience reviewed concerning the obstacles to the automatic factory and the probability of their elimination. The following conclusions seem justified:

1. The larger the company and the greater the financial resources at its command, the more capable it is to meet and overcome the major obstacles. The cost obstacle becomes weaker as the financial strength of the firm increases. The ability to coordinate all of the skills necessary for achieving increased automaticity also appears to rise in proportion to the financial resources of the company.

2. Measuring and understanding the complexities of the production process continues to be one of the most unassailable obstacles. Related to this is the dearth of qualified engineers. These are obstacles which are less subject to removal on the strength of finances alone.

3. Manufacturers are interested in the financial implications of changes in their production processes. Hence, financial return is the key factor. This has the effect in many instances of limiting automaticity considerably short of the automatic factory.

4. The market for a firm's products affects that firm's ability to automatize in two major ways:
   (a) The aggregate demand, in terms of volume, affects the company's opportunity to employ special-purpose equipment. The greater the demand for a particular product the easier it becomes to economically justify the use of special-purpose equipment on that product. Long runs versus short runs is the issue. One way of circumventing this issue is through the use of flexible machinery which can easily be adapted to different products. Project Tinkertoy, in which the modular design or "building block" concept is employed, is a modern example of one way in which flexibility has been achieved. Modular design, in that situation, has established "a series of mechanically standardized and uniform modules (or building blocks), producible with a wide range of electrical characteristics." The MIT milling machine is another answer; however, until the prohibitive cost of the machine can be reduced (about $800,000) its application will be limited.
   (b) The less concerned the market is with style, the greater leeway a firm has to redesign its products to meet the demands of automatic processes. The progress of the automobile companies has been achieved primarily in connection with internal parts of the finished product. Project Tinkertoy involves products where the function performed is the critical consideration and not the visual effects of the design.

5. The specific context of each individual company is the framework within which automaticity, if at all, must manifest itself. This means the primary burden for instituting process changes leading to the automatic factory must lie with the company. Instrument manufacturers and machine-tool builders can do a great deal on their own, particularly with standard tools. But even in these cases, the "standard" tools must be tailored to the specific conditions of the company. In the numerous instances where the tools and instruments must undergo major adaptations to meet the company situation, the focal point is, self-evidently, the company. The implications of this circumstance are considerable. In the larger companies, their own "automation departments" can assume the burden of directing and coordinating specific projects. The smaller companies, while they can benefit somewhat from the pioneering effort of the large companies, must utilize other means before they can expect substantial progress. The so-called "automation consulting firm" may eventually be the answer for their predicament.

TURBINE-BLADE TEMPERATURE

Inductive commutator permits measurement of temperatures of turbine blades rotating at 25,000 rpm.

INSTRUMENTATION SYSTEM for remote indication of gas-turbine blade temperatures has recently been designed by M. L. Greenough of the National Bureau of Standards for the Navy Bureau of Ships. The system includes special high-temperature resistance thermometers that withstand large centrifugal forces (100,000 g's), an inductive commutator that transmits signal information from the high-speed rotor (25,000 rpm.) to external stationary equipment, and electronic circuitry that interprets the telemetered signals as temperature measurements. Tests on turbines under actual operating conditions indicate that temperature measurements may be made with the instrumentation system to an accuracy of better than ± 25 deg. F. at temperatures up to at least 1400 F., where more conventional methods used on lower-speed machinery are not applicable. Electrical and mechanical portions of the system were developed by L. A. Marzetta and F. H. Bayhi; the resistance thermometers by M. Davis and H. A. Bowman.

The Inductive Commutator

At low speeds, slip-ring or commutator and brush arrangements are used commonly to transfer data from moving parts. At high speeds, however, or in the presence of oil or water vapor, maintenance of good contact for reliable signal transfer becomes difficult.

New alternatives are their inductive counterparts—the "inductive slip-ring" and the "inductive commutator": the latter has been developed more fully at NBS.

The inductive commutator consists of a number of pairs of input and output coils on the rotating shaft (Fig. 1) with one stationary set of energizing and information-receiving coils mounted on the turbine frame. Rotation of the shaft brings each coil pair into and out of coupling with the stationary coils. Each channel or set of rotating coils is sampled periodically with rotation; thus signal information is sequential in nature. The shaft may be run in either direction without modification of the unit.

Electrical Circuit

The electrical circuit of the inductive coupling units is simple (Fig. 3). One stationary coil is excited with current at 160 kc.; the other stationary coil develops the output voltage. On the rotating structure, the coil pairs are electrically connected together and shunted by the variable-resistance thermometer element. One of the rotating pair couples electromagnetically with the exciting stationary coil, the other with the output coil. The result is that the amount of energy transferred through the device is governed by the resistance of the thermometer element when its particular rotating coil pair is coupled to the stationary coils. The voltage output is nearly a linear function of thermometer resistance, and is independent of the speed of rotation.

In order to make the output voltage independent of the strength of excitation of the input coil, one of the channels is used for calibration, and a fixed, known resistance is substituted for one of the temperature-sensitive elements. Thus the ratio of the output of any of the signal channels to that of the calibration channel is the true measure of the resistance of the sensing element. This ratio is easily determined by adjusting the excitation for a constant output from the calibration channel, whereupon the signal channel output may be read directly. The gain-determining features obtained through the use of the calibration channel also provides a means of compensation

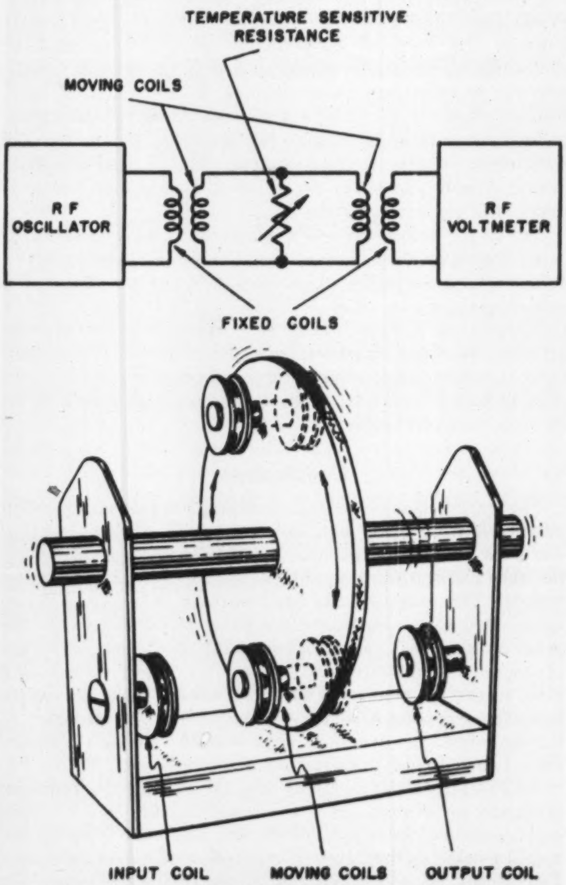

Fig. 1. Basic principle, showing inductive commutator. Oscillator energizes input (fixed) coil at left. Magnitude of signal induced at output coil (measured by r-f. voltmeter) depends on resistance of resistance thermometer.

TELEMETER

for changes in the oscillator frequency and for changes of resistance in the commutator windings.

In the NBS instrumentation system, five rotating coil pairs provide a four-channel measurement system; the fifth channel is reserved for calibration. Surrounding the commutator coils are five synchronizing coils which allow the selection of any one channel for observation. The selection is accomplished by gating the source of r-f. excitation when the chosen rotating pair comes between the fixed coils. Gating is achieved by mounting a short piece of high-permeability material around the outside of the rotating disk so that it is centered under a synchronizing coil whenever the signal coil pair is at maximum coupling. Therefore the inductance of any one synchronizing coil is raised for a part of each shaft revolution, and during this time the excitation oscillator is gated on. Thus the desired channel may be selected by switching the appropriate synchronizing coil into the synchronizing circuit. This method of channel selection is independent of the speed and of the direction of rotation.

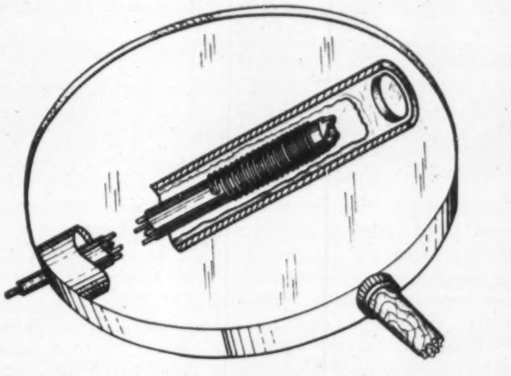
Fig. 2. Cutaway view of miniature resistance thermometer.

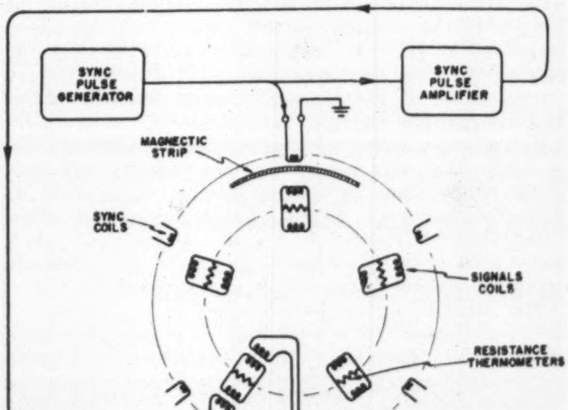

Fig. 3. Block diagram of telemetering system.

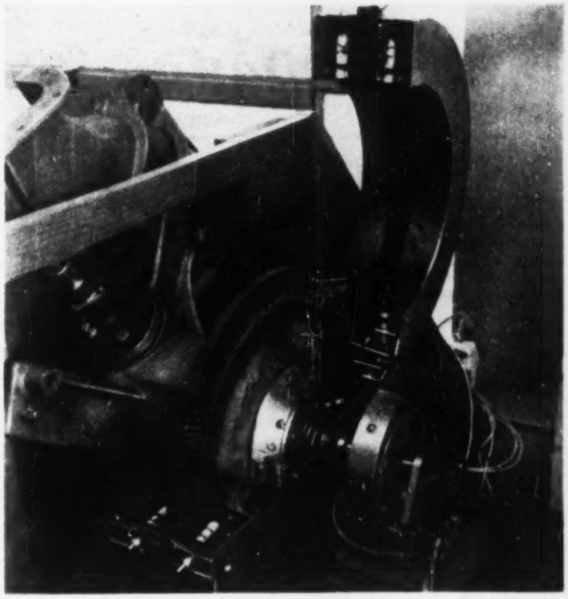
Fig. 4. Typical installation.

Resistance Thermometers

The resistance thermometer is contained in a thin-walled tube of inconel approximately 0.040 inch in diameter—about the size of an extra-thin automatic pencil lead. The temperature-sensing element consists of a 24-turn coil of 0.001-in.-diameter platinum or rhodium wire in a helix about 0.024 inch in diameter and 1/8 inch long; thus the effective temperature sensing area is small. The element is embedded in "A-417" cement, a ceramic composition developed by the National Bureau of Standards as a protective coating for metals in high-temperature service. Calibration measurements at 1400 deg. F. at 40,000 *g*'s indicate good adherence, no softening, and no deleterious chemical action with the coil materials used.

Performance

Static accuracy and reliability tests for a number of thermometer elements indicate a variation from the mean response of less than 10 degrees F. over a range from 800 to 1500 deg. F. There does not appear to be any appreciable change in the characteristics for at least a dozen runs on any one thermometer. Further tests to determine their permanency are under way.

Thermo-resistive elements have been made and tested to withstand about 40,000 *g*'s at 1400 deg. F. inside a miniature oven mounted on a centrifuge. The tests also showed no appreciable strain effect under these conditions. If a strain effect were to become evident as measurement techniques become more refined, a minor speed correction could be applied.

To date, facilities have not permitted parallel operation of the thermo-resistive system and a calibrating thermocouple system. Instead, the approach has been to mount the former in a turbine assembly, run the turbine under measured operating conditions, and then install the latter and run the turbine again under identical conditions. This has been carried out for temperatures up to 1400 F. at forces up to 30,000 *g*'s. With either system the variation between runs is of the same order as the agreement between the two systems—about 15 to 25 degrees F.

Instrumentation in

STREAM-POLLUTION CONTROL

In pollution abatement, all else is secondary to the stream. Necessary instrumentation includes recording of water-course flows and stream constituents to provide adequate data for flexible stream control.

JOHN J. BAFFA
Consulting Engineer,
New York City.

ONE of the developments of modern times is the accelerated establishment of stream-classification standards compatible with water usage. Some of these standards contain quantitative criteria; some pollution-control authorities promulgate sewage and industrial waste-treatment-plant effluent standards. Both types of criteria for pollution control have given rise to problems of application and administration and to technical and legal controversy.

Water Courses

Pollution-abatement requirements apply to tidal waters, lakes, rivers and ground water.

Instrument applications to water courses include continuous measurement of tide levels, lake levels, stream stages, ground-water levels, stream velocities, and stream flows. Use of wind-direction instruments to determine travel of pollution has been the practice for many years. Less universally used in the receiving water itself are continuous recording mechanisms for conductivity, oxidation-reduction potential, salinity, pH, temperature, and photoelectric-cell equipment for recording color intensity and turbidity.

Flows in many large streams have been recorded for years by the U. S. Geological Survey. Similar measurements in small streams by pollution-control agencies would be of considerable value.

Conductivity measurements often can be correlated with specific constituents, as can oxidation-reduction potentials. The importance of temperature to dissolved-oxygen considerations, and the importance of pH in relation to specific contaminants and activities of algae, make these continuous records invaluable. The continuous recording of dissolved oxygen, the continuous monitoring for radioactive contamination, and continuous microscopic detection of undesirable microcosms will one day be commonplace.

Stream Control Problems

Continuous recording of stream quality and flows provides data for flexibility of stream control. For example, many rules and regulations tend to provide for all-time record drought conditions, and thus impose considerable burden of cost on stream users from the standpoints of both capital costs of treatment works and operating costs. Continuous flow measurements can anticipate drought conditions, and allow flow control where regulating reservoirs exist. There are several locations in the country where it is possible to pump from one watershed to another when conditions require. Trickling filters and activated-sludge plants can be operated to control effluent B.O.D. and nitrification in relation to treatment-plant operating economy. Where industrial wastes are lagooned, they can be discharged at proper times compatible with stream flows and stream quality.

The allocation of stream capacity under changing conditions poses a difficult problem to stream administrators. Continuous recording of related factors which define local characteristics is to be highly recommended.

Discussion

by A. N. DIACHISHIN
Principal Engineer, Interstate Sanitation Commission.

The information we desire is of two general categories—inanimate and animate. The inanimate includes flows and all the physical characteristics of the stream, such as the concentrations of dissolved and colloidal materials. The animate includes data about the host of complex biological activities that occur in a stream.

The importance of recording is not to be underestimated. For example, the Interstate Sanitation Commission has been conducting a weekly survey in Upper New York Harbor since the winter of 1952. At a sampling station in the Narrows, some twenty feet below the water surface and at least a mile removed from any pollution source, there was a variation of from 28 to over 90 percent of dissolved-oxygen saturation. Even the concentration of chlorides varied from about 7,500 to 15,000 parts per million at this sampling location. Measurements or estimates are made of (1) the strength and direction of the current, (2) air temperature and velocity, (3) water temperature, (4) pH, (5) suspended solids, both total and volatile, (6) chloride concentration, (7) dissolved-oxygen concentration, (8) B.O.D., and (9) most probable number of coliform organisms.

The primary biological characteristic of a stream that is widely used, and indeed is almost solely relied upon in the classification of bathing beaches, is in itself an indirect measurement. I speak of the determination of the "Most Probable Number of Coliform Organisms," which purportedly is an indication of the number of pathogenic organisms present in the sample of water tested.

The problem of the measurement of the density of pathogenic organisms is not solved. At present, we cannot measure the nature of coliform organisms in a given sample with any degree of reliability. In addition to the large variability of the Most Probable Number Data itself, still another removal from the original waters themselves must be made—that is, a ratio must be applied to the Most Probable Number to obtain an estimate of the numbers of any particular pathogen. Instruments are needed to measure and record more accurately these biological indicators.

Presented at the Second Conference on Instrumentation, Manhattan College, N. Y., 1954.

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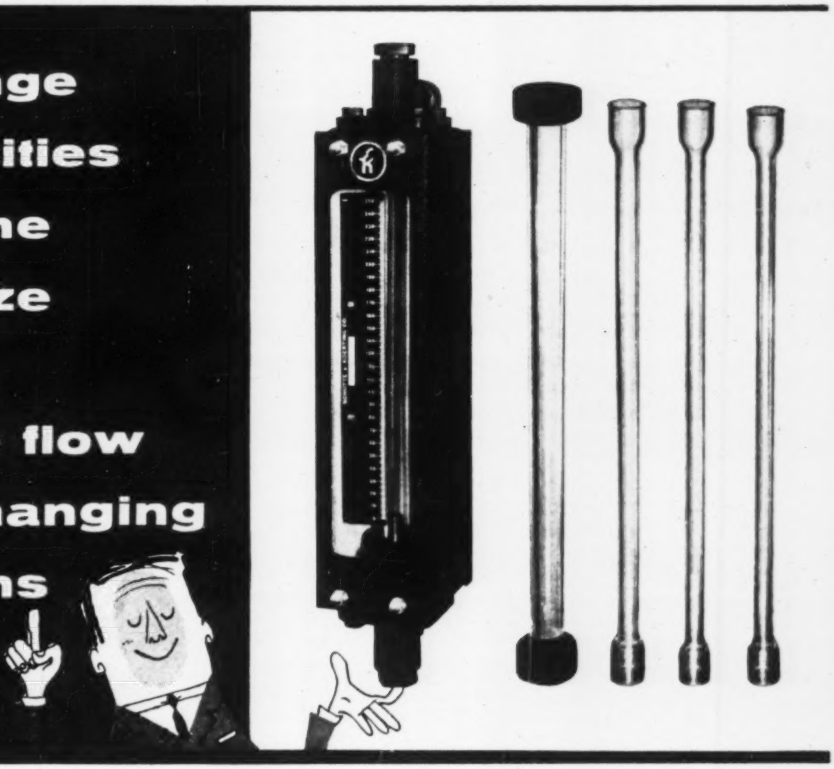

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. . . Heavy Gauge, Safety Glass Windows provide excellent view of tube, rotor and scale.

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ELECTRONIC CONTROL SYSTEMS

The electronic control system comprises an electronic conversion unit, a recorder or indicator, controller, and electro-pneumatic transducer. Each element is discussed, as are cost factors, applications, and future potentialities.

ROGER GILLILAND
The Swartwout Company

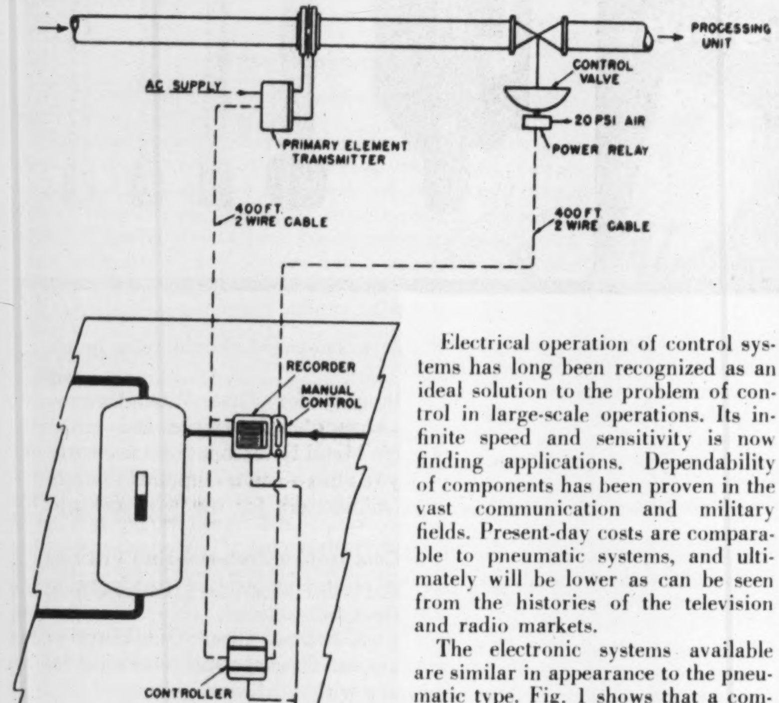


Fig. 1. A typical flow-control system.

DEMAND for more automatic operation of a given process with resulting requests for more accurate, faster, more dependable instrument components, has given us the present-day selection of methods of control. Pneumatic controllers have been refined to provide each advancement required by process designers.

Electrical operation of control systems has long been recognized as an ideal solution to the problem of control in large-scale operations. Its infinite speed and sensitivity is now finding applications. Dependability of components has been proven in the vast communication and military fields. Present-day costs are comparable to pneumatic systems, and ultimately will be lower as can be seen from the histories of the television and radio markets.

The electronic systems available are similar in appearance to the pneumatic type. Fig. 1 shows that a complete system has (1) a transmitter located at the point of measurement, (2) a recorder, controller, and manual panel in the control room, which is probably at a remote location, and (3) an electro-pneumatic transducer at the final control element. All transmission is accomplished instantaneously in the form of electrical quantities. Corrective valve action occurs at the same instant that the slightest process deviation occurs. Sensitivities of an entire control loop have been checked to be in the order of one part in twenty-eight thousand, in customers' evaluation tests.

Electronic Conversion Unit

The development of the electrical signal, the comparison with the desired value, and the modulation of the final control element can be accomplished in a variety of ways. Fig. 2 shows a conversion portion of an electrical transmitter. The variable to be measured is converted to a force by means of a diaphragm, bellows, or bourdon tube applied to lever AA at its lefthand end. This force causes a movement of lever AA about the fulcrum BB; this movement is transmitted and amplified through a series of spring pivots until at lever HH a much larger movement results. The core of the differential transformer is attached to lever HH at LL and will move up and down within the coil of the transformer as the variable changes.

Recording or Indicating

Fig. 3 shows one method of recording or indicating the electrical signal. A servo-type device gives the best accuracy and the highest speed of response without instability. An amplifier compares the transmitter signal to another signal generated by the pen or needle position. This amplifier produces an output which is directly proportional to the difference between the indication and the signal being received.

This differential amplifier output is fed to a phase-sensitive rectifier which measures the magnitude of the difference, while also indicating the higher of the two variables. This rectifier controls the power output of a power amplifier which, in turn, drives the pen or needle through a rotary-type solenoid. Due to the high amplification of the electronic system there is considerable force available to drive the mechanism.

The adjustable-response network is a feedback which reduces the amplification of the power amplifier at higher frequencies so that pen or needle fluctuations can be eliminated when pulsations are present in the process.

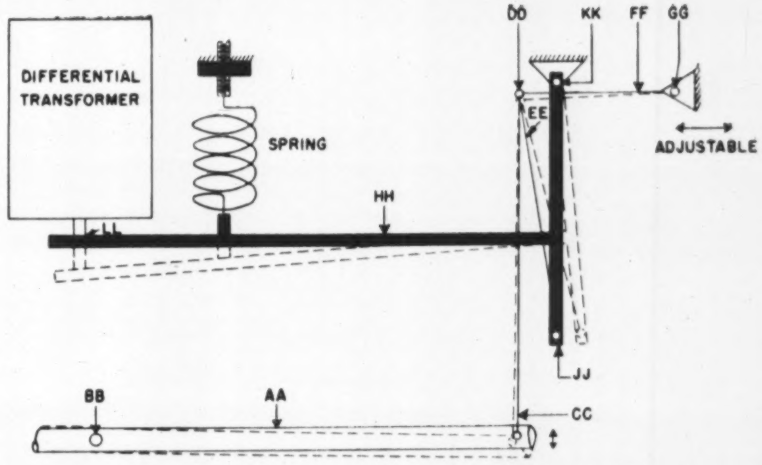

DIFFERENTIAL TRANSFORMER
SPRING
LL
HH
DD
KK
FF
GG
EE
ADJUSTABLE
JJ
BB
AA
CC

Fig. 2. Differential-transformer-type electronic conversion unit, or transducer.

The Controller

The heart of the system is the controller, although it is only as good as the signal it receives and the final control element it positions. Fig. 4 shows one type of electronic controller. The signal received from the transmitter is compared to a desired value as received from a manually adjusted setpoint unit. The difference between these signals is amplified as determined by the setting of a degenerative feedback network around the proportional amplifier. This adjustment is comparable to proportional band used in pneumatic instrumentation.

The phase of the amplified output signal is determined and its magnitude is a measure of the difference. A phase-sensitive rectifier receives the amplifier signal and converts it to a d-c. signal of a magnitude proportional to the value of the input, and positive or negative with respect to ground corresponding to the polarity of the input.

This output is fed into a rate amplifier (when rate action is desired), which is a 1:1 ratio unit when the input is constant. An adjustable feedback network delays feedback during periods of changing input signals, causing a high amplification for an adjustable period of time, thereby providing a rate-action control function. This resistor-capacitor feedback network delay will gradually disappear and the amplifier will return to its 1:1 ratio.

The rate-action-amplifier output is the input to a voltage and a power amplifier with an adjustable feedback network that supplies the reset action. This network provides high amplification with a steady-state or slowly changing input, and lower amplification on rapidly changing signals. It provides the controller with an initially wide proportional band for fast changes, which will slowly reduce itself to a narrow proportional band as the process upset subsides. The time in which this occurs is adjustable by means of the reset calibration available from the front of the controller. The final controller output is developed completely electronically, without use of a moving part.

Electro-pneumatic Transducer

The diaphragm valve, like the pneumatic controller, has advanced. Today's electronic systems recognize the present proven acceptability of this final-control element in the petroleum and chemical fields by utilizing electro-pneumatic transducers on the controller output to convert to the air pressure necessary to modulate such valves. Fig. 5 shows one of the designs of such a transducer. The controller output is wired to a moving coil in a permanent-magnet field. This coil is connected to a lever which transmits a force proportional to the controller output to an air portion of the unit. A diaphragm produces an equal force by changing the air pressure in the pilot section. This variable air pressure is imposed on a diaphragm in the booster section to produce a similar or higher air pressure in the large volumes necessary to move diaphragm motor valves rapidly.

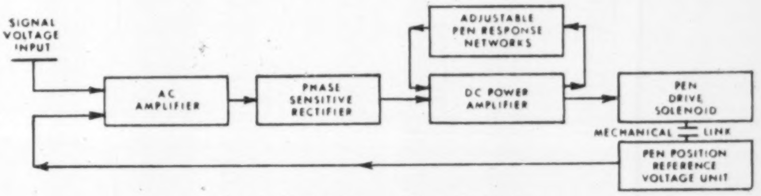

SIGNAL VOLTAGE INPUT
AC AMPLIFIER
PHASE SENSITIVE RECTIFIER
ADJUSTABLE PEN RESPONSE NETWORKS
DC POWER AMPLIFIER
PEN DRIVE SOLENOID
MECHANICAL LINK
PEN POSITION REFERENCE VOLTAGE UNIT

Fig. 3. Electronic recorder or indicator.

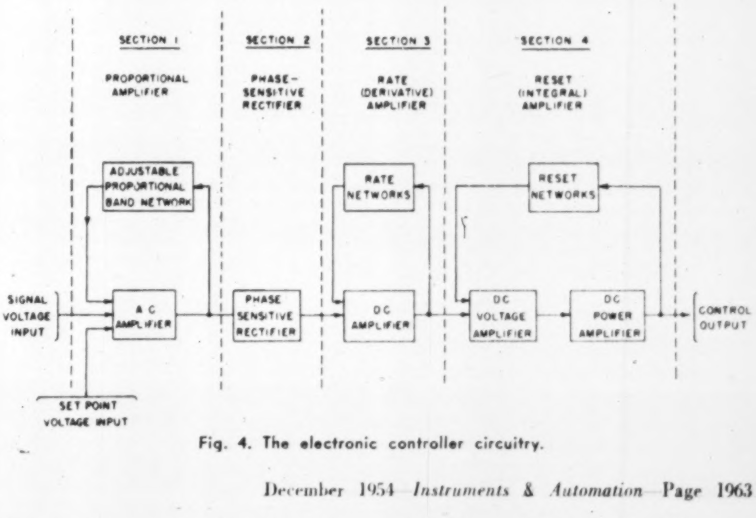

SECTION 1
PROPORTIONAL AMPLIFIER
SECTION 2
PHASE-SENSITIVE RECTIFIER
SECTION 3
RATE (DERIVATIVE) AMPLIFIER
SECTION 4
RESET (INTEGRAL) AMPLIFIER
ADJUSTABLE PROPORTIONAL BAND NETWORK
RATE NETWORKS
RESET NETWORKS
SIGNAL VOLTAGE INPUT
A C AMPLIFIER
PHASE SENSITIVE RECTIFIER
DC AMPLIFIER
DC VOLTAGE AMPLIFIER
DC POWER AMPLIFIER
CONTROL OUTPUT
SET POINT VOLTAGE INPUT

Fig. 4. The electronic controller circuitry.

> *January Meeting*: Thursday, the 27th, Los Angeles Harbor Junior College, Wilmington, Calif.
>
> *Feature*: J. G. Ziegler, Coast Engineer for Taylor Instrument Companies, will discuss "Instrument Man's Position in Industry."

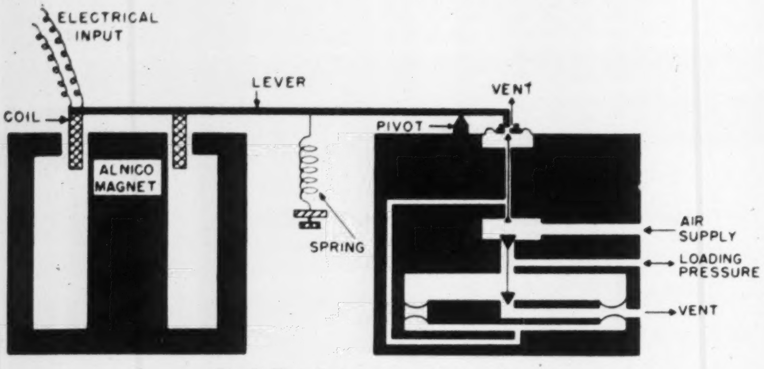


Fig. 5. The electro-pneumatic transducer.

A similar design can be tied into valve-stem travel to create an electro-pneumatic positioner. The self-powered modulating valve operator (an electric motor or electro-hydraulic pump drive) has not had the intensive demand for refinement as has the diaphragm unit and has lagged behind the needs of the industry. Now that control systems are available to utilize operators of this type, some new developments are being released, and greater strides forward can be expected in the future. Self-contained operators would eliminate the need for a centralized supply of motive power and the complicated distribution systems now required in large-scale installations.

Magnetic amplifiers are available for electric heating loads and electronic motor speed controls for pumps, belt conveyors, and similar rotational applications. Strain gages, gas analysers, radiation pickups, current transformers, and a host of other specialized electronic primary measurement devices can provide signals to be indicated or controlled.

Cost Factors

One of the deterrents to the development and use of electronic instrumentation in the past has been its high cost. Careful design of electronic transmitters and transducers have provided units which are suitable for Class-1, Group-D, Division-1 location, but have kept them completely available for servicing and maintenance at the process installation. Transmitters can be set and weight-calibrated without being removed from their position. Costs, even under limited production, are comparable to similar pneumatic types.

Applications

Electronic installations are now in full operation in refineries in this country. A graphic panel is installed on a Platforming Unit at Rock Island Refining Corporation in Zionsville, Indiana. A console-type panel has been employed on the Catforming Unit at Atlantic Refining Company in Port Arthur, Texas. Another electronic process has been installed and checked at a west coast oil company, although complete operation of this unit will not be obtained until construction work on other portions of the installation is completed this fall. Other units are now in various stages of construction.

A petroleum pumping company has two electronically controlled pumping stations in operation at the present time, and five more under construction. This company felt that electronic instrumentation was more suitable than the pneumatic counterpart because the pumping stations are operated remotely and are not fully attended by an operator. They believed that the most automatic operation could be accomplished by means of electricity. (Manufacturers of regulating valves now offer electric-motor and electro-hydraulic valves which would prove more suitable for booster pumping stations because they would eliminate the cost of air compressors and their associated equipment.)

Trained personnel were available for electronic equipment because of the microwave system used for voice and signal transmission in the petroleum transportation system. Each station consists of four pumps which are started and stopped remotely. A regulating valve is installed in the discharge line of each station. A downstream pressure controller positions this valve if the station discharge pressure reaches the maximum operating limit. This controller can be over-ridden by a suction pressure controller which will reduce the throughput to a value which will maintain the minimum station suction pressure to the pumps. Each motor-driven pump is equipped with a motor current adapter unit which receives the output of a current transformer in the motor circuit. These adapters and their controllers can over-ride the suction and discharge pressure system and position the discharge valve, thereby eliminating the need for the operator's presence when pumps are started or motor overloads occur. A comparable pneumatic over-ride system would not be as economic or as fundamentally simple as this electronic solution.

Most of the pipeline stations built within the last few years could benefit from complete or partial electronic control.

The Future

We have seen that electronic instrumentation can provide all the features demanded in present-day pneumatic control. We can logically ask: "What more can electronics provide"? However, the present advantages should not be overlooked. The sensitivity and speed of response of an electronic control loop adds stability to the process, which can result in higher product quality and easier operation. For instance, the Platforming Unit at Rock Island Refining Company was put on the line easier and more quickly than any of its many predecessors.

Flexibility of adding, subtracting, cascading, ratioing or over-riding electrical signals opens new methods of accomplishing an end result which was prohibitive before electronic control advanced to its present state of development.

The immediate future will bring many more advantages. Today's electronic systems are being applied to installations designed for slower instrumentation. Frequency-response data on process components and control-system engineering are reducing the flywheel effects designed into new units, and electronic systems with their 10-cycle-per-second response make the original investment savings greater. It is entirely possible that the present-day pneumatic-controller functions of proportional band, reset, and rate action may be amended and expanded to a new field of electronic-control functions more suited to future control problems.

Data-reduction units for gathering process variable values and tabulating them automatically at set intervals of time are entering the petroleum field today. They are electronic devices which require electronic signals and, therefore, electronic instrumentation.

The inherent advantages of instantaneous response, low cost, great flexibility, and high accuracy of electronic systems will produce an ever-widening utilization of the electronic approach to process control in the petroleum, chemical, and allied fields.

Test Your I. Q.

Instruments
and AUTOMATION

The IQ of an instrument man is very different from that of most people—and, as all instrument men know—much higher. It does not even stand for the same thing—the IQ of an instrument man is his INSTRUMENT QUOTIENT. The answers to every question are to be found in the editorial matter and articles in this issue, and answers are given on page 1984.

Question 1

The unexpected but basic advantage of electronic controllers revealed by the Rock Island installation is
- (a) no air lines to freeze up in cold weather
- (b) easier and cheaper maintenance resulted
- (c) higher rate-response settings could be used
- (d) all the above

Question 2

In diffraction gratings, the term "blaze angle" refers to the angle between the grating normal and the
- (a) normal to the groove face
- (b) normal to angle of incidence
- (c) angle of diffraction
- (d) angle of refraction

Question 3

Basic advantage of an inductive commutator over brush-and-slip-ring commutators is that the inductive commutator
- (a) is independent of exciting field strength
- (b) has less wear problems
- (c) uses simpler circuitry
- (d) all the above

Question 4

The most-advanced type of machine for contemporary automaticity in the machine-tool industry is the
- (a) single-station combination-tool machine
- (b) dial-type multiple-station machine
- (c) trunnion-type multiple-station machine
- (d) transfer machine

Question 5

The chief problem existing in machine-tool automation is
- (a) down time due to tool changing
- (b) transfer of pieces between stations
- (c) automatic inspection devices
- (d) size of index tables

Question 6

The binary number 1111 is equivalent to the decimal number
- (a) 4
- (b) 8
- (c) 15
- (d) 30

Question 7

The binary number 100001 is equivalent to the decimal number
- (a) 6
- (b) 7
- (c) 33
- (d) 65

Question 8

The sum, in binary form of the binary numbers 1111 and 100001 is
- (a) 101111
- (b) 110000
- (c) 111111
- (d) 111100

Question 9

The binary number 110000 is equivalent to the decimal number
- (a) 48
- (b) 96
- (c) 128
- (d) 256

Question 10

The product of the binary numbers 1111 and 100001 is, in binary form,
- (a) 101110
- (b) 1111110
- (c) 11110111
- (d) 111101111

Question 11

The binary number 111101111 is equivalent to the decimal number
- (a) 35
- (b) 70
- (c) 140
- (d) 495

Question 12

A diode matrix is a device that
- (a) activates one line or lead out of a group
- (b) activates one flip-flop out of a group
- (c) uses diodes to amplify
- (d) uses a matrix to amplify

Question 13

An unsolved problem in stream-pollution control, and one for which instruments are not available, is measurement of
- (a) probable number of coliform organisms
- (b) biological oxygen demand
- (c) dissolved oxygen concentration
- (d) suspended solids, total and volatile

Question 14

In the NBS turbine-blade temperature telemeter, the function of the movable magnetic strip is to induce a signal in
- (a) one output coil
- (b) one sync coil
- (c) all output coils
- (d) all sync coils

Question 15

In the NBS turbine-blade temperature telemeter, the 160-kc. gated oscillator is gated by the
- (a) peak detector
- (b) sync coil
- (c) input coil
- (d) output coil

Question 16

In the NBS turbine-blade temperature telemeter, the output voltage is made independent of the excitation voltage by using a
- (a) ratio-type measurement
- (b) regulated supply voltage
- (c) 160-kc. oscillator
- (d) resistance thermometer

Question 17

In the NBS turbine-blade temperature telemeter the function of the sync coils is to
- (a) synchronize the speed of the turbine
- (b) select one channel
- (c) calibrate the instrument
- (d) couple the output to the voltmeter

Question 18

The term USP as applied to chemicals and reagents refers to
- (a) U. S. Pharmacopoeia
- (b) Underwriters Standard Purity
- (c) U. S. Purity
- (d) Underwriters Standard Pharmacopoeia

Question 19

The term NF as applied to chemicals and reagents refers to
- (a) Nonpurified Formulation
- (b) Nonviscous Formulation
- (c) Nonanalytical Formulation
- (d) National Formulary

Question 20

Basic feature that limits size of dial-type and trunnion-type multiple-station machines is the indexing error associated with
- (a) large-diameter tables and trunnions
- (b) gaging-technique limitations
- (c) time to change tools
- (d) all the above

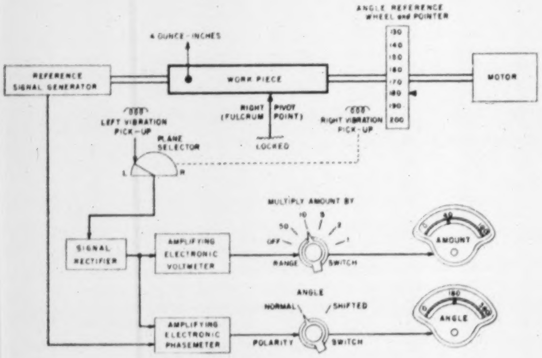
Briefs . . .

Instruments and AUTOMATION

Balancing Machine

Dynamic unbalance occurs at more than one point and can only be detected when the part is rotating. This unbalance is expressed in terms of ounce-inches for each of two perpendicular planes (left and right) located some distance apart. Correction is made separately in each of these planes. The result is a rotating part which is dynamically balanced.

A balancing machine provides a means to determine both the amount and angular location of the resultant forces stemming from unbalance. Balance is then achieved by either adding or removing the equivalent of the indicated weight at the known location(s).


ANGLE REFERENCE WHEEL and POINTER
130
140
150
160
170
180
190
200
OUNCE-INCHES
REFERENCE SIGNAL GENERATOR
WORK PIECE
MOTOR
LEFT VIBRATION PICK-UP
RIGHT (FULCRUM
PIVOT POINT)
LOCKED
RIGHT VIBRATION PICK-UP
PLANE SELECTOR
L
R
MULTIPLY AMOUNT BY
OFF
50
10
5
2
1
SIGNAL RECTIFIER
AMPLIFYING ELECTRONIC VOLTMETER
RANGE
SWITCH
0
50
100
AMOUNT
ANGLE
NORMAL
SHIFTED
AMPLIFYING ELECTRONIC PHASEMETER
POLARITY
SWITCH
0
180
360
ANGLE

Basically, the Electodyne is a two channel amplifier which is actuated by the signal received from the Velocity Pick-Up for the plane of correction selected (left or right). This signal is proportional to the unbalance forces exerted by the work piece.

The first, or amount channel, rectifies the signal and visually indicates it on the Amount Meter which is graduated from 0 to 100. This is an accurate indication of the amount of unbalance, which can be directly translated into terms of ounce-inches of unbalance or any convenient equivalent.

Simultaneously, the second or angle channel forms the same signal into a single pulse and indicates the phase displacement between this pulse and a reference pulse generated on the machine spindle. This value, shown directly on the Angle Meter (graduated from 0-360°), is an accurate indication of the angular location of the resultant forces causing the unbalance in the selected plane of correction. (*From new 24-page Bulletin 49, Tinius Olsen Testing Machine Co., Willow Grove, Pa.*)

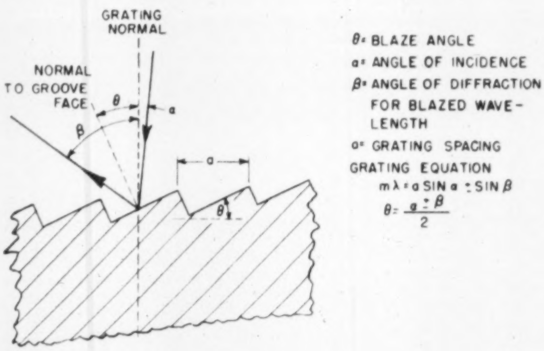
For this literature circle **401** on inquiry card.

Diffraction Gratings

The problem of ruling diffraction gratings is an old one. For more than 130 years, men have tried to rule the large number of straight, equally spaced, parallel lines required to form a grating. The names of Fraunhofer (1821), Nobert (1846), and Rutherford (1870) are mentioned among those who first ruled small gratings. Rowland, at Johns Hopkins University, working in the period from 1882 to 1901, was the first person to succeed at the task of ruling high quality gratings. In addition to plane gratings, he invented and ruled the first concave gratings, which were to be so useful for many types of spectroscopic work.

In the twentieth century many people have attempted to rule gratings with varying amounts of success. A very small proportion are able to rule satisfactory gratings 100mm or more in width. Of these, only those at Johns Hopkins University, Mt. Wilson Observatory, and Bausch & Lomb Optical Co. can now produce high quality gratings with 175mm or more of ruling with high resolving power.

CROSS SECTION DIAGRAM OF DIFFRACTION GRATING


GRATING NORMAL
NORMAL TO GROOVE FACE
θ
α
β
a
θ
θ = BLAZE ANGLE
α = ANGLE OF INCIDENCE
β = ANGLE OF DIFFRACTION FOR BLAZED WAVELENGTH
a = GRATING SPACING
GRATING EQUATION
mλ = a SIN α ± SIN β
θ = (α ± β)/2

The problem was solved by constructing an underground grating ruling laboratory equipped with very precise temperature control and modern vibration isolation. This installation has been successful in maintaining the ruling engine temperature constant to better than ± 0.01 C for periods exceeding 2 weeks, while the maximum amplitude of vibration of the ruling engine is less than 1/40 of a micron, (1/10 fringe). . . . More than 5 years of work have been performed on the ruling engine.

Modern diffraction gratings are blazed by controlling the groove face angle so as to concentrate the spectral energy in the desired region of the spectrum.

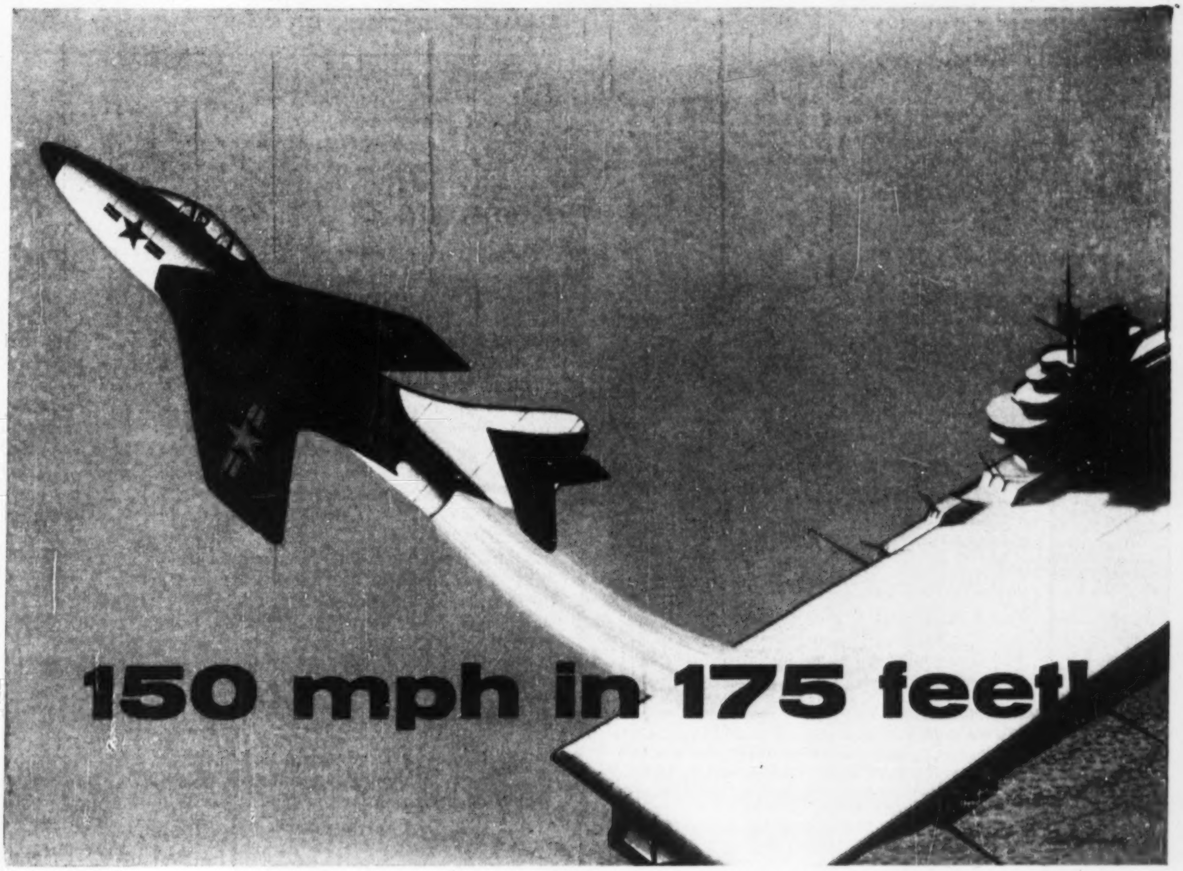
The resolving power of a grating is a measure of its ability to separate two spectral lines with a very small wavelength difference existing between them. (*From new 22-page Brochure D-261, covering history and principles of gratings, Bausch & Lomb Optical Co., Rochester 2, N. Y.*)

For this literature circle **402** on inquiry card.

Paper Electrophoresis

Paper electrophoresis supplies another dimension to chromatography in general by utilizing the differences in electrical mobility of chemical substances. These differences permit separation of compounds which have like chromatographic behavior due to similarity of their partition coefficients and adsorption.

Generally in procedures for paper electrophoresis a small sample containing the compounds to be resolved is applied to a strip of buffer-saturated paper. The paper strip is placed over a support with its ends immersed in electrode vessels containing buffer solution. The pH of the buffer is adjusted to effect the desired migration of the compounds to be separated and at the same time to provide an electrolyte for carrying a potential. This potential is applied to electrodes located in the vessels containing the buffer solution. Under the influence of the voltage gradient, compounds applied to the paper will migrate at rates relative to their charges. At the end of a given time interval the current is disconnected, the paper removed, and the separated zones located and identified by some one of the conventional procedures used in paper chromatography, i.e., spraying with ninhydrin for amino



That is the speed at which the latest steam catapult launches a jet fighter. Such speed requires precision and split-second action to control the temperature and pressure of the steam which drives the catapult. Hagan Automatic Control has been chosen for this important function.

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- Programmed control systems for simulated flight conditions and trajectory tests.
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- Portable thrust stands for aircraft thrust measurement.

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For more information circle 74 on inquiry card.

acids, p-anisidine for carbohydrates, dye stain for proteins, etc. (*From new 16-page Catalog AC-54, Schaar & Co., 754 W. Lexington St., Chicago 7, Ill.*)

For this literature circle **403** on inquiry card.

Reagents and Chemicals

Definitions of Quality: "*Baker Analyzed*" *Reagent* defines chemicals of the highest quality. . . . *CP* defines chemicals of high purity which do not meet the stringent requirements for the Baker Analyzed Reagent label. . . . *USP* and *NF* define chemicals which conform to the requirements of the current U. S. Pharmacopoeia and National Formulary respectively. . . . *Purified* defines chemicals of good quality in the absence of official standards. . . . *Technical* defines chemicals of selected commercial quality, physically clean and of reasonable chemical purity.

Here is a list of the principal bulk chemicals . . . supplied to industry in tonnage quantities. . . . Acetic acid, Acetophenetidin . . . Acetylsalicylic acid . . . Aluminum hydroxide . . . etc.

Many thousand of dollars can be saved if the proper care is exercised in storing chemicals. Chemicals affected by extreme temperatures are listed. . . . (*From new 244-page "Specification Catalog," J. T. Baker Chemical Co., Phillipsburg, N. J.*)

For this literature circle **404** on inquiry card.

Photoelectric Trace Recorder

The Photoelectric Tracing Recorder is a novel recording instrument producing an immediately visible, continuous record of light-pointer movements on ordinary paper with a useful face 180 mm (7¼ in.) wide. The Tracing Recorder is used in conjunction with a mirror-galvanometer to record minute currents and voltages.

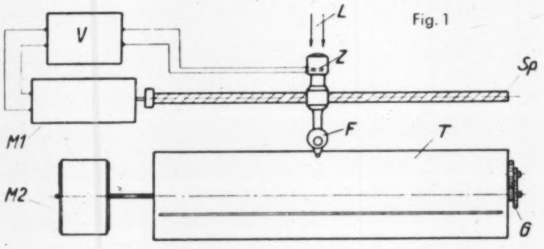


Fig. 1

The principle of the instrument is shown in Fig. 1 where L denotes a pencil of light hitting a CdS crystal cell Z. The photoelectric current generated by the cell governs the amplifier V driving the motor M1 with its spindle Sp which moves the tracing unit incorporating the cell and the capillary pen. (*From 4-page form List 47/54, Federal Tel & Radio Co., 100 Kingsland Rd., Clifton, N. J.*)

For this literature circle **405** on inquiry card.

Electric Heat

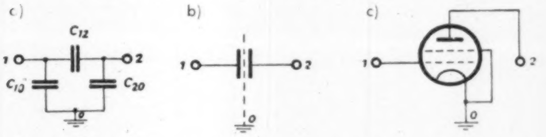
Problem of making a paint baking oven adaptable to a wide variety of parts is one frequently encountered in metal finishing operations. Here was the situation faced by an instrument manufacturer: a wide assortment of parts has to be finish-baked, there's little volume in any given one, and a high quality finish must be maintained on all.

The job was previously done by air-drying the painted parts. Naturally, this was found to have drawbacks—drying time varied widely with different parts, sizes and paint formulas; a large amount of space was required for stacking; and, of course, production crawled. . . . Then, enlisting the aid of automatic electric heat, the company built a highly flexible oven to handle a wide range of parts in production quantities. The oven is the recirculating type. Two Chromalox Electric Air Blast Heaters, selected because they are so readily adaptable to air duct installations, were placed in the oven plenum chamber. With a capacity of 20 kilowatts each, they supply uniform heat to the air and thus throughout the oven. (*From new 4-page issue No. 54 of "Chromalox News," Edwin L. Wiegand Co., 7500 Thomas Blvd., Pittsburgh 8, Pa.*)

For this literature circle **406** on inquiry card.

Capacitance Meter

Instrument KKH measures the shielding factor capacitance C12 between two terminals (1 and 2) in the range from 3 x 10^{-4} to 30 uuf. It also measures ground capacitance C20 or . . . C10. In practice most objects are measured as shown in Fig. b . . . constituting the shielding factor capacitance. . . . An important case is the determination of the shielding factor capacitance of tubes. With this instrument the capacitances between any electrodes of the tube . . . can be measured. (*From new 160-page loose-bound catalog presenting complete line of Rohde & Schwarz a-f. and r-f. instruments, Federal Tel. & Radio Co., Instrument Div., 100 Kingsland Rd., Clifton, N. J.*)



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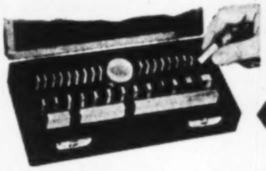

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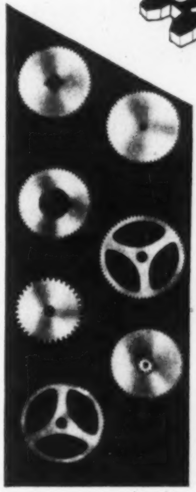

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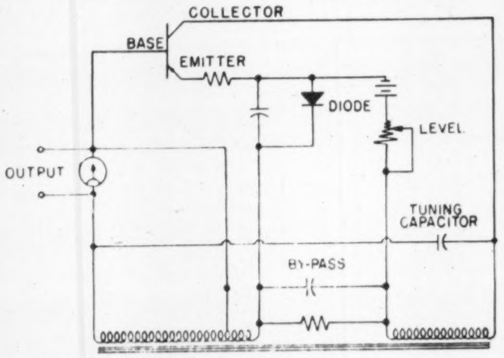
For more information circle **77** on inquiry card.

curately to ±0.25% of input voltage. Any voltage from 100 to 500 volts may be read in 39 10-volt full scale steps. *(From new 4-page Bulletin 101, Arga Div., Beckman Instruments, 220 Pasadena Ave., S. Pasadena, Calif.)*

For this literature circle **408** on inquiry card.

Transistor Audio Oscillator

For several years, the General Radio Company has carried on an experimental development program in transistor circuits and their applications. The first instrument to result from this program is the Type 1307-A Transistor Oscillator, a pocket-size source of test voltage at 400 and 1000 cycles. . . . The circuit is equivalent to a Hartley oscillator circuit. *(From new 8-page Vol. 29, No. 3 issue of "Experimenter, General Radio Co., Cambridge, Mass.)*



For this literature circle **409** on inquiry card.

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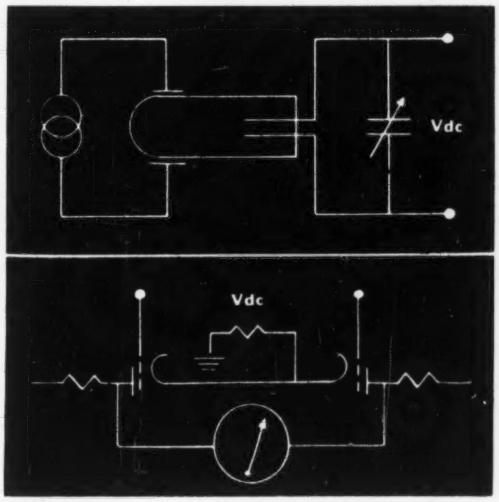

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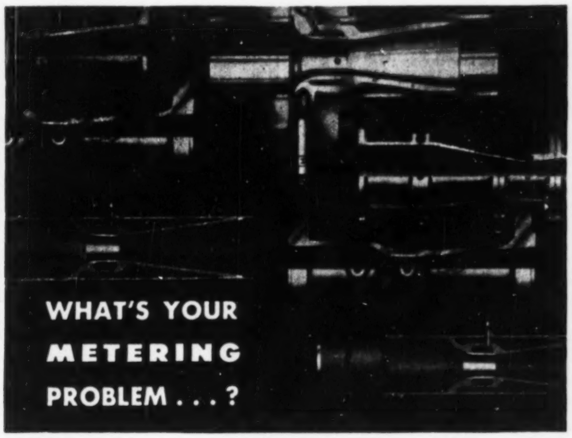

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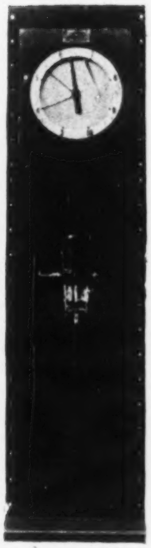

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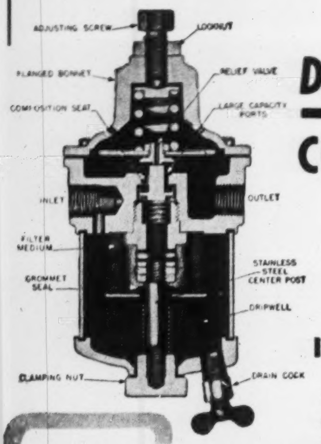
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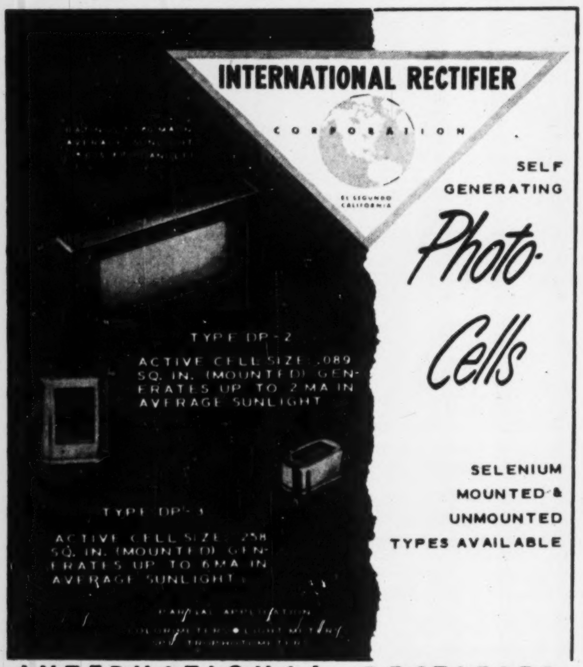
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For more information circle **85** on inquiry card.

signal of approximately 10 volts per micromicrofarad change in capacitance. (*From new 2-page Data Sheet* 103-1, *Decker Avation Corp.*, 1361 *Frankford Ave., Phila., Pa.*)

For this literature circle **410** on inquiry card.

Manufacturing Control

In IBM Accounting, facts are recorded on IBM cards in the form of punched holes. The preparation of records and reports by automatic IBM Accounting Machines actuated by these cards is today's most effective method of meeting the requirements of modern record-keeping. . . . Daily reports of progress against a schedule, in order number sequence, are machine prepared from the Final Assembly Control Cards. These report the start of completion of key assembly operations. . . . IBM Indicating Clocks, Attendance Time Recorders, Time Stamps, and Job Cost Recorders may be operated in IBM Self-regulating Time Systems or as units independent of a master control. The functioning of utilities may be automatically programmed, providing for considerable savings in consumption. (*From new 32-page booklet Form* 32-5608-1, *International Business Machines Corp.*, 590 *Madison Ave., N. Y.* 22, *N. Y.*

For this literature circle **411** on inquiry card.

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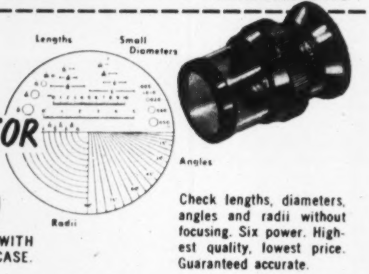
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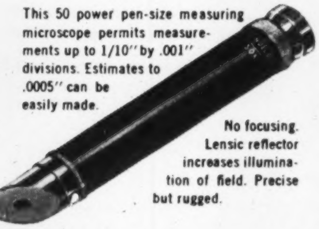

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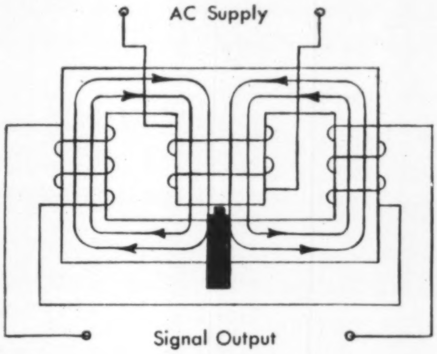
For more information circle **86** on inquiry card.

cause of their electrical characteristics. *Borosilicate glasses*: heat resisting, low coefficient of expansion; used for fresnel spot-light lens and other lens applications. *Lime glasses*: general use, low cost, fired colors; applications—battery cover, car light lens, etc. (*From 8-page brochure "Custom Glass," The Lancaster Lens Co., Lancaster, Ohio.*)

For this literature circle **412** on inquiry card.

Position-sensitive Transducer

The Metrisite is a position-sensitive transducer . . . . may be used with most AC resistance bridge measuring instruments such as the Foxboro Resistance Dynalog.



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0-60, at 250 M.V.

D.C. MILLIAMPERES
0-1.2-12-120, at 250 M.V.

D.C. AMPERES
0-12, at 250 M.V.

D.B.
−30, +4, +16, +30, +44, +56, +70 (For Direct Reading of Output Levels.)

*OHMS
0-1000-10,000 (4.4-44 center scale)

*MEGOHMS
0-1-100 (4400-440,000 Ohms center scale)

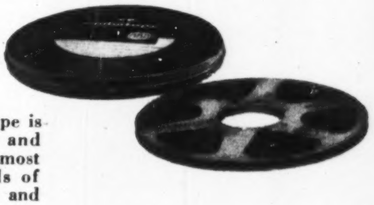
TRIPLETT
ELECTRICAL INSTRUMENT COMPANY
Bluffton, Ohio

For more information circle **88** on inquiry card.

NOW—*a data recording tape that's guaranteed*

DEFECT-FREE!

Type **EP audiotape** *provides the EXTRA PRECISION that you need for dependable magnetic data recording*



Type EP Audiotape is manufactured and tested to meet the most exacting standards of quality, uniformity and freedom from dropouts or surface imperfections. Subjected to repeated checks on an automatic defect counter, it is guaranteed *defect-free!*

Packed in Polyethylene bags and magnetic-shield metal cans. Available on cellulose acetate base (1½ mil) or Mylar* polyester film, in 1, 1½ or 2 mil base thickness. Standard widths from ¼ inch up – to your specified tolerances.

**Du Pont Trade Mark*

AUDIO DEVICES, Inc.
444 Madison Ave., New York 22, N. Y.

Send for Bulletin No. 207

For more information circle **87** on inquiry card.

MARSHALLTOWN

10
15
20
5
25
30
INCHES OF WATER

DIAPHRAGM GAUGE

For Accurate Pressure Measurement in Ounces or Inches of Water

Available in standard dials (reading in inches of water) 0-15" -0-30" -0-60" -0-100" -0-160" . . . also in ounce graduated dials from 15 ounces to 5 pounds. 2½", 3½" and 4½" dial sizes mounted in black enameled steel case.

Marshalltown Figure 83 is an extremely sensitive gauge that uses a carefully seasoned bronze diaphragm to accurately measure very low pressures. It is used extensively on many types of natural gas installations for checking low pressures.

Write for details and price.

LOOK TO MARSHALLTOWN FOR ONE OF THE MOST COMPLETE LINES OF INDICATING PRESSURE GAUGES MADE!

MARSHALLTOWN MANUFACTURING CO.
MARSHALLTOWN 3, IOWA

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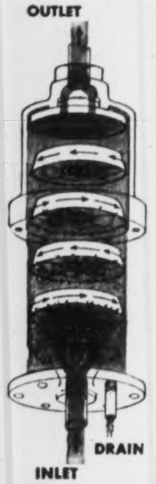
EQUIPMENT LASTS LONGER
...PERFORMS BETTER...
when the
ARIDIFIER
SCRUBS, CLEANS AND DRIES
On Air and Gas Lines

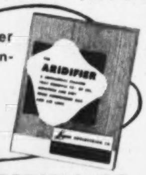


LASTS LONGER because...
The Aridifier's patented centrifugal-baffle action traps 92% of all dirt, oil, scale and water in gas or compressed air . . . and drains off these troublemakers *before* they can damage tools and equipment.

PERFORMS BETTER because...
The Aridifier protects tools against the freezing, fouling, caking and corrosion caused by dirt and foreign matter . . . assures the clean, dry air and gas that means better spray work, painting, lacquering, sand blasting, air cleaning, and similar operations.

Easily installed, the Aridifier maintains itself. 10 models. Capacity range; 7 CFM to 17,000 CFM.

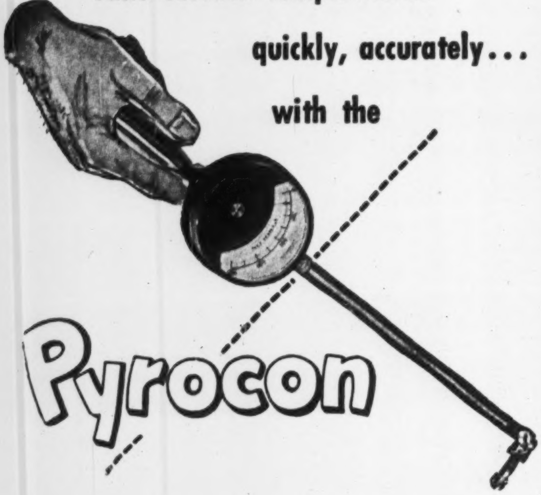
Learn HOW the Aridifier scrubs with a patented centrifugal-baffle action.
Write for This Catalog Now!



Logan ENGINEERING CO.
4921 W. Lawrence Ave., Chicago 30, Ill.

For more information circle 90 on inquiry card.

Take surface temperatures
quickly, accurately...
with the



Pyrocon

The handy Alnor Pyrocon is unequaled for quick, accurate reading of all surface temperatures . . . whether surfaces are metallic or non-metallic, flat or curved. Accurate temperatures are easily understood on the Pyrocon's direct reading scale face . . . without interpolation or need of conversion tables. A wide selection of thermocouples and extension arms permits adaptation to many types of service. For complete details and prices, send for Bulletin No. 4257. Illinois Testing Laboratories Inc., Room 518, 420 N. LaSalle Street, Chicago 10, Ill.

Alnor PRECISION INSTRUMENTS FOR EVERY INDUSTRY

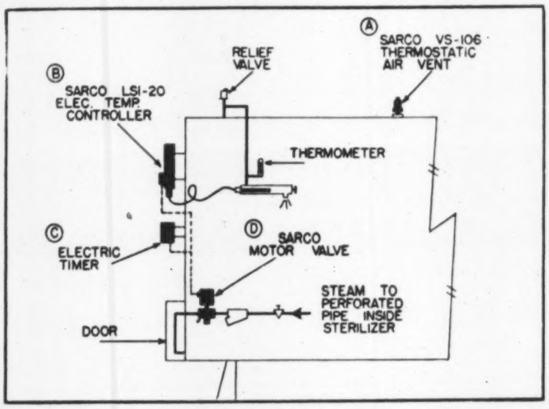
For more information circle 91 on inquiry card.

voltage being proportional to the flux linking the coils. Inasmuch as the two coils are in series, with induced voltages opposed to each other, the output voltage is proportional to the flux difference in the two legs. This in turn is proportional to the displacement of the conducting loop provided that the air gap flux is uniform . . . . full scale response has been obtained with armature movements of 1 microinch. *(From new 4-page brochure, Graydon Smith Products Corp., W. Concord, Mass.)*

For this literature circle **413** on inquiry card.

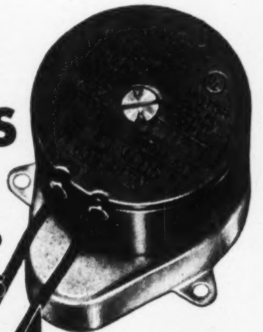
Sterilizer Control

Problem: How to provide the sterilizer with a dependable automatic temperature control and timer hook-up which would cost not more than $250.00. Solution: See illustration *(From "Case History No. 147" Sarco Co., Inc., Empire State Bldg., New York 1, N. Y.)*


Ⓐ SARCO VS-106 THERMOSTATIC AIR VENT
RELIEF VALVE
Ⓑ SARCO LSI-20 ELEC. TEMP. CONTROLLER
THERMOMETER
Ⓒ ELECTRIC TIMER
Ⓓ SARCO MOTOR VALVE
STEAM TO PERFORATED PIPE INSIDE STERILIZER
DOOR

For this literature circle **414** on inquiry card.

NOW!...
4-6 WEEKS DELIVERY
ALL STANDARD Cramer MOTORS



Cramer
SYNCHRONOUS MOTORS
The R. W. CRAMER CO., Inc.

WRITE FOR NEW BULLETIN

The Type 112 Synchronous Motor recently announced by The R. W. Cramer Company is now in full production. Expanded facilities for standard motors now make possible prompt deliveries of small or large volume orders.
Write for new Bulletin PB-110.

Cramer TIMING DEVICES
SPECIALISTS IN TIME CONTROL
The R. W. CRAMER CO., Inc.
BOX 5, CENTERBROOK, CONNECTICUT
14CR54

For more information circle 92 on inquiry card.

Pneumatic Controller Standards

1.2 The purpose of this standard is to establish:

(a) Standard operating pressure ranges for pneumatic intelligence transmission systems, pneumatic motor operators, and pneumatic positioning relays.

(b) Standard air supply pressures (with limit values) corresponding to the specified operating pressure spans or ranges for the devices to which this standard applies.

(From new 6-page Tentative Standard "Air Pressures for Pneumatic Controllers and Transmission Systems," Recorder-Controller Section, SAMA, 522 Fifth Ave., New York 36, N. Y.

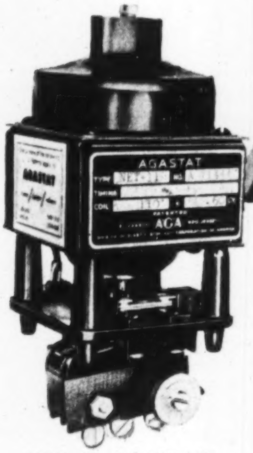
For this literature circle **415** on inquiry card.

Magnetic Amplifier

MRC "Micromag" is a new magnetic low level DC amplifier which has been especially designed to operate under adverse environmental conditions. Three basic types are available. Type MM-411 has a maximum voltage gain in excess of 4000. The input voltage sensitivity is 20 microvolts. Input resistance is 20 ohms. This amplifier is recommended for amplification of signals from thermocouples and current measuring shunts. Type MM-421 has a maximum voltage gain in excess of 1250. It has an input voltage sensitivity of 60 microvolts. Input resistance is 180 ohms. This amplifier is recommended for the amplification of signals from strain gauges, resistance thermometer bridges, and other general applications. Type MM-431 has an input current sensitivity of 0.1 microamperes. Input resistance is 2000 ohms. This unit is recommended for application in electronic equipment.

All models are powered from 400 cps and require 6.3 volts, 0.0005 amperes excitation. *(From new 4-page Bulletin EB-201, Magnetic Research Corp., 200 Center St., El Segundo, Calif.)*

For this literature circle **416** on inquiry card.



NET-11 AGASTAT

NEW!

TWO STEP

AGASTAT

Trademark

TIME DELAY RELAYS

Single units for applications requiring a sequence of time delay relay periods—such as sequential starting of motors—or an adjustable momentary impulse, as in operating air valves of air cylinders on indexing machines. Time delay range of from 0.1 seconds to 10 or more minutes, with a secondary delay period up to 15 seconds. Compact, lightweight pneumatically timed units, low in cost and remarkably versatile.

Write for specifications—and ask our application engineers for help with your timing problem. Address Dept. A14-129.

AGA
DIVISION

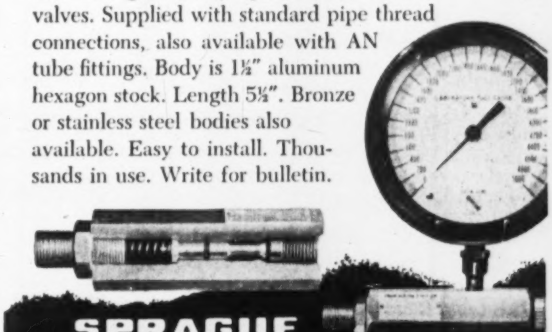
Elastic Stop Nut Corporation of America
1027 Newark Avenue, Elizabeth, New Jersey
Pioneers in pneumatic timing.

For more information circle **93** on inquiry card.

PROTECT

EXPENSIVE GAGES

SPRAGUE SHUT OFF VALVES automatically cut out gages and other pressure-sensitive instruments when fluid pressures go beyond their operating limits. Automatically open when pressure is again within approx. 80% of set cut-out points. Available for any pressure setting between 10 PSI. and 5000 PSI. Save valuable man hours. Eliminate opening and closing manually operated shut off valves. Supplied with standard pipe thread connections, also available with AN tube fittings. Body is 1½" aluminum hexagon stock. Length 5½". Bronze or stainless steel bodies also available. Easy to install. Thousands in use. Write for bulletin.



SPRAGUE
Engineering Corporation
1144 WEST 135TH STREET, GARDENA, CALIFORNIA

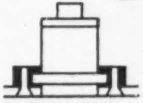
For more information circle **94** on inquiry card.

These CEC miniature precision instrument-type

pressure pickups

cover a wide performance range

PICKUP WITH FLUSH MOUNTING FLANGE
PICKUP ONLY
PICKUP WITH PIPE ADAPTER



FLUSH MOUNTING DIAGRAM

Consolidated pressure pickups feature a-c or d-c excitation—full-scale pressure ranges from 5 to 5,000 PSI—linearity within 1%—negligible sensitivity to acceleration and vibration—wide temperature range from −65°F to +250°F—output 20 millivolts with 5-volt excitation—flush-type diaphragm as standard construction—stainless steel, corrosion-resistant construction—overload protection—high frequency response—variable-resistance types—calibration certificate with each pickup. Electrical principle is unbonded strain-gage windings connected in a four-arm bridge as the active element. Write for Bulletin CEC 1552-X1 and price list.

Pickup Type	*Range*	*Dimensions*
4-310 gage pressure pickup	**5 to 250 PSI**	**0.5" diam. x 0.7"**
4-311 gage pressure pickup	**5 to 5,000 PSI**	**0.625" diam x 0.875"**
4-312 absolute, differential, or gage pressure pickup	**5 to 250 PSI**	**0.5" diam x 0.7"**

Consolidated Engineering
CORPORATION
300 North Sierra Madre Villa, Pasadena 15, California

For more information circle **95** on inquiry card.

MANUFACTURERS' NEW LITERATURE

In this department we report new literature, pertaining to instrumentation, received from the manufacturers. We urge readers to request ONLY those bulletins which will be of value to them. Use the Postage-free Order Card on Page 1995.

Requests for literature FROM ABROAD should be made on company letterhead and mailed DIRECTLY to the manufacturers.

AUTOMATION

Electric Process-Control System. New 16-page Booklet ND4 (7) presents principles and operation of new "Series 60" electric process controller which includes an indicator or indicating recorder, primary element, and final control device. Circuits are given for proportional, reset, and rate actions.—Leeds & Northrup, 4907 Stenton Ave., Phila. 44, Pa.

Circle **417** on inquiry card.

Process Instrumentation. New 8-page Bulletin DM035 presents maker's complete line of process instruments—"Free-Vane" controllers, "Metagraphic" control systems, "Dynamaster" potentiometers, and instruments for pH, humidity, flow, level, temperature, etc.—Bristol Co., P.O. Box 1790, Waterbury 20, Conn.

Circle **418** on inquiry card.

Meter Relays. New 52-page Catalog 3-A describes and illustrates maker's contact meter-relays and controls, indicating and controlling pyrometers, and panel meters. Includes principles, applications, and specification sheet.—Assembly Products, Inc., P.O. Box 191, Chagrin Falls, Ohio.

Circle **419** on inquiry card.

Pneumatic Controllers. New 2-page Specification Sheet 163-1 describes maker's "ElectroniK" circular-chart pneumatic controllers. Includes listing of control modes available.—Minneapolis-Honeywell Regulator Co., Industrial Div., Phila. 44, Pa.

Circle **420** on inquiry card.

Program Control. New 2-page Specification Sheet 287-1 lists specifications of maker's pneumatic time-pattern transmitter unit for controlling a program by transmitting a pre-determined program to adjust set points of one or more control instruments.—Minneapolis-Honeywell Regulator Co., Industrial Div., Phila. 44, Pa.

Circle **421** on inquiry card.

Servomechanisms, Process Instruments. New 36-page Catalog 954 SM describes and illustrates maker's large line, including field-wound miniature motors, potentiometers for telemetering, and computers, thermocouples, pressure and temperature instruments, electronic transducers, precision gears, and electronic hygrometer.—Burton Mfg. Co., 11201 W. Pico Blvd., Los Angeles 64, Calif.

Circle **422** on inquiry card.

High-torque Pneumatic Positioner. New 4-page Bulletin S-19 describes and illustrates maker's "Series 77" final drive unit for accurate positioning and regulation of valves and dampers requiring a high-torque positioner.—Republic Flow Meters Co., 2240 Diversey Parkway, Chicago 47, Ill.

Circle **423** on inquiry card.

Electronic Process Control. New 4-page issue of "Wheelco Comments" (Vol. 14, No. 6) features articles on "Model 407 Capacitrol" for electric proportioning control.—Wheelco Instruments, Barber-Colman Co., Rockford, Ill.

Circle **424** on inquiry card.

Furnace Control. New 4-page Bulletin 2250 describes and illustrates maker's stoker-fired furnace humidification control system for reducing deposits on boiler tubes.—Foxboro Co., Foxboro, Mass.

Circle **425** on inquiry card.

Machine Process Control. New 4-page folder describes maker's line of automatic control devices—timers of cam, drum, and intervat types; temperature and pressure controllers for presses, kilns, and ovens; air diaphragm motor valves; high-pressure hydraulic valves; low-pressure water and steam valves for use on hydraulic compression presses.—Seely Instrument Co., Inc., 377 Fourth St., Niagara Falls, N. Y.

Circle **426** on inquiry card.

Engine Controller. New 4-page Bulletin 649A describes maker's "Universal" automatic gas and diesel engine controller with cubicle construction.—Alexander F. Barron, 53 W. Jackson Blvd., Chicago, Ill.

Circle **427** on inquiry card.

Servo System. New 2-page Data Sheet DR 100 describes maker's "HC 100 Series" servo system comprising chopper, amplifier, and servo motor.—Hazatrol Corp., 215 Market St., San Francisco, Calif.

Circle **428** on inquiry card.

Relay Control Box. New 2-page Data Sheet 11493 describes maker's redesigned electronic relay control box for controlling electric heater circuits, timing devices, thermoregulators and liquid-level controls.—Precision Scientific Co., 3737 W. Cortland St., Chicago 47, Ill.

Circle **429** on inquiry card.

Recording Controller. New 2-page Bulletin 62 describes maker's potentiometer pyrometer and resistance-thermometer controllers with either two-position or pulse-proportional control action.—Thermo Electric Co., Inc., Saddle River Township, Rochelle Park Post Office, N. J.

Circle **430** on inquiry card.

Process Instrumentation. New 28-page issue of "Taylor Technology" (Vol. 7, No. 1-2) features article on primary elements for flow measurement.—Taylor Instrument Cos., Rochester 1, N. Y.

Circle **431** on inquiry card.

Telemetering System. New 12-page Bulletin ATIC-929 "Selective Telemetering Applications" (Vol. IV, Sec. 7) features articles on supervisory control systems that permit remote control of valves, motors, etc.—Motorola Communications & Electronics, Inc., 4501 W. Augusta Blvd., Chicago 51, Ill.

Circle **432** on inquiry card.

Photoelectric Edge Control. New 4-page bulletin describes maker's "Linar Edgetrol" photoelectric edge guidance for accurate printing, rerolling, slitting, punching, etc.—Airlectron, Engineering, Inc., 110 Washington St., New York 6, N. Y.

Circle **433** on inquiry card.

Surge Control. New 4-page bulletin "Magnilastic Newsletter" (Vol. 2, No. 20) illustrates and describes maker's pressurized "Hydropads" for pipe line and instrument protection where there are sudden velocity changes in fluid pipe lines.—Cook Electric Co., 2700 N. Southport Ave., Chicago 14, Ill.

Circle **434** on inquiry card.

Roller Gear Drives. New 20-page Catalog 105 describes maker's line of standard roller gear drives for high-speed precision indexing of automatic production machinery.—Ferguson Machine & Tool Co., P. O. Box 191, St. Louis 21, Mo.

Circle **435** on inquiry card.

Indexing Machine. New 4-page bulletin describes maker's Type "A" "Trans-o-Mator" multiple-station transfer machine.—Ferguson Machine & Tool Co., Inc., P. O. Box 191, St. Louis 21, Mo.

Circle **436** on inquiry card.

MOTORS

Motors. New 26-page Catalog El-3A describes and illustrates maker's line of induction and torque motors. Includes electrical specifications and frame dimensions.—Electric Indicator Co., Inc., Springdale, Conn.

Circle **437** on inquiry card.

Synchronous Motors. New 8-page Brochure PB-110 describes maker's synchronous motors for instrument and industrial control applications. Includes "Type 112" standard synchronous motor, "Type 142" clutch unit motor, and "Type 152" dual motor.—R. W. Cramer Co., Inc., Centerbrook and Ballouville, Conn.

Circle **438** on inquiry card.

Motor Speed Control. New 8-page issue of "Experimenter" (Vol. 29, No. 5) features article on "Unmounted Motor Speed Controls For Assembly

Into Other Equipment."—General Radio Co., 275 Massachusetts Ave., Cambridge 39, Mass.

Circle 439 on inquiry card.

Speed-Regulated Motor. New 2-page Bulletin SC-5-754 describes features and performance of maker's 1-hp., 12,000-rpm. "Type SC-5" motor.—Dalmotor Co., 1344 Clay St., Santa Clara, Calif.

Circle 440 on inquiry card.

VALVES, TRAPS

Valves, Air Motors. New 28-page Bulletin SP-50 "Spec-Book" describes dimensions and specifications of maker's cylinder-type air motors, pilot valves, solenoid valves, and 4-way valves. Includes large air-consumption chart.—Bellows Co., 222 W. Market St., Akron, Ohio.

Circle 441 on inquiry card.

Control Valve. New 2-page bulletin covers maker's control valve with "Isoforce Actuator" that uses Belbfram principle. Includes features, characteristics, and accessories.—Foster Engineering Co., 835 Lehigh Ave., Union, N. J.

Circle 442 on inquiry card.

Ball Valves. New 6-page illustrated Folder 10M-4-54 describes maker's ball valves with full round flow, quick opening and closing.—Rockwood Sprinkler Co., 38 Harlow St., Worcester 5, Mass.

Circle 443 on inquiry card.

Globe Valves. New 16-page bulletin describes maker's "Section B" stainless-steel globe and stop valves. Includes pressure, velocity, and discharge conversion tables.—Associated Valve & Engineering Co., 1150 W. Marquette Rd., Chicago 21, Ill.

Circle 444 on inquiry card.

Needle, Check, Plug Valves. New 20-page Catalog A243 describes maker's line of precision check valves, relief valves, needle valves, on-off valves, and plug valves for precision applications.—Kohler Co., Kohler, Wisc.

Circle 445 on inquiry card.

Steam Traps. New 8-page Bulletin 255A describes and illustrates maker's thermodynamic steam traps for high pressure and superheated steam mains. —Sarco Co., Inc., Empire State Bldg., N. Y. 1, N. Y.

Circle 446 on inquiry card.

Solenoid Valve. New 8-page Bulletin AV300R illustrates and describes maker's "Electroaire" valve—a solenoid-operated air-control unit.—Bellows Co., 222 W. Market St., Akron, Ohio.

Circle 447 on inquiry card.

TEMPERATURE

Temperature Measurement. New 24-page Bulletin 101 discusses measurement, recording, and controlling of process temperatures by mercury-bulb instrumentation. Includes basic principles.—Partlow Corp., New Hartford, N. Y.

Circle 448 on inquiry card.

Low-temperature Containers. New 126-page proceedings of symposium on "Low Temperature Test Methods and Standards for Containers" contains

---

SENSITIVE

D' Arsonval

METER-RELAY

Jeweled Moving Coil Armature

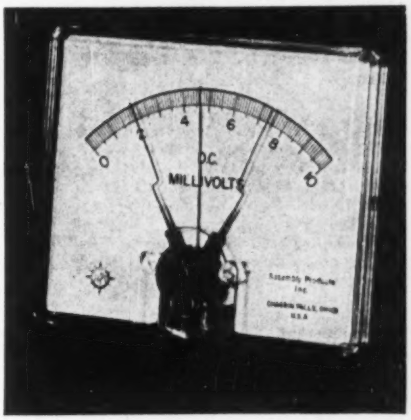
0.2 Microamperes
(0/20 scale range)

0.05 Millivolts
(0/5 scale range)

A.C. D.C.
(voltage - current)

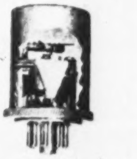
Thermocouples
(R.F. or temperature)

Adjustable
(90° scale arc)

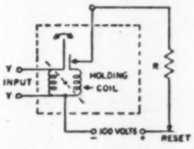


Model 451-C, (4½ inch) double contact, 0/10 DC Millivolts, as used in Vacuum Gauge made by Hastings Instrument Co., Inc., Hampton, Va., used to maintain pressure in a vacuum system.

The contact meter-relay as made by Assembly Products is an indicating meter with built-in micro-contacts which can be set to operate at any point of indication on the scale.



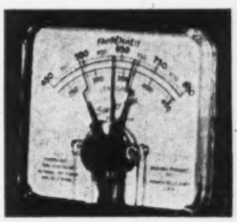
Model 266, plug-in, (non-indicating) hermetically sealed, with shock mounted movement. Suited to marine or aircraft or other mobile installations.



Single contact meter-relay schematic.

Made like a conventional panel meter, it can be substituted for an existing meter in most circuits and will add relay action for over or under limit or automatic control.

A locking coil gives high contact pressure. Spring action in the contacts gives forceful separation. Contacts are released by breaking the circuit to the locking coil, either manually or by an automatic interrupter switch.



Model 351-C, (3¾ inch), double contact, suppressed zero millivoltmeter, with bimetal compensation for thermocouple reference junction. Dial calibrated 450-850° Fahrenheit (also Centigrade), for Iron-Constantan thermocouple. Used in control of temperature of THERMO DIMPLER made by Zephyr Mfg. Co., Inc., 201 Hindry, Inglewood, Calif.

Model 263, (2½ inch), double contact, (non-indicating) used in Model 653 SILVERCEL BATTERY CHARGER CONTROL manufactured for the Navy by Franklin Transformer Mfg. Co., Minneapolis, Minn.

Send for 16-page
Bulletin G-6
AUTOMATIC
Contact Meter-Relay
CONTROL

Model 261-C, (2½ inch), single contact, high limit, 0/200 DC Microamperes as used in Consolidated Engineering Corp., Pasadena, California Model 21-220 Mass Spectrometer.

ASSEMBLY PRODUCTS, INC.
CHESTERLAND 10, OHIO
Phone: Cleveland, Ohio
HAmilton 3-4436

*Yardney Silvercel—Reg. Trademark of Yardney Electric Corp.

For more information circle 96 on inquiry card.

MANUFACTURERS' NEW LITERATURE

articles on packaging aspects of modern combat, facilities for low-temperature research, effect of low temperature on container components, etc. —Quartermaster Food & Container Institute for the Armed Forces, 1819 W. Pershing Rd., Chicago 9, Ill.

Circle **449** on inquiry card.

Temperature Control. New 8-page Catalog CC describes maker's temperature controls and allied equipment for industrial heating and refrigeration. Includes recording and indicating controls, thermometers, "Saf-t-flame" gas pilots, bulb installation, accessories, etc.—Partlow Corp., 2 Campion Rd., New Hartford, N. Y.

Circle **450** on inquiry card.

Micro Optical Pyrometer. New 4-page brochure describes and illustrates maker's micro-optical pyrometer for lab and plant use in measuring temperatures of targets smaller than 0.001 inch in diameter.—Pyrometer Instrument Co., Inc., Bergenfield, N. J.

Circle **451** on inquiry card.

Charts, Gages, Thermometers. New Data Sheets 954, 954-2, 954-3 and 954-4, describe available portable potentiometers, round-dial indicating controllers, etc.; lists size, range pressure and quantity of indicating and recording gages; price and quantity of laboratory and dial thermometers; gives information on tempilstiks, tempil pellets, and tempilaq.—Claud S. Gordon Co., 3000 S. Wallace St., Chicago 16, Ill.

Circle **452** on inquiry card.

Thermocouple Wire. New 4-page issue of "Service" "Vol. II No. 1) describes maker's "Serv-Rite" insulated thermocouple wire and thermocouple assemblies; custom-built furnaces; and sand testing equipment.—Claud S. Gordon Co., 3000 S. Wallace St., Chicago 16, Ili.

Circle **453** on inquiry card.

Temperature Controllers. New 2-page Data Sheet ND 46(4) describes maker's "Speedomax Model S" program-control system which offers flexibility in setting rate of heating, length of soak period and rate of cooling in batch-type heating processes.—Leeds & Northrup Co., 4934 Stenton Ave., Phila. 44, Pa.

Circle **454** on inquiry card.

Thermistor-operated Temperature Controller. New 2-page bulletin describes and illustrates maker's "Series 560" indicating controller for kilns, ovens, air heaters, etc., featuring thermistor pickup and proportioning control.—Fenwal, Inc., Ashland, Mass.

Circle **455** on inquiry card.

Thermostats. New 2-page Bulletin LL-303 describes maker's "Stemco Type B" bimetal thermostats and "Stemco Tip-Off" safety switch for use in heaters and electric appliances. —Stevens Mfg. Co., Inc., Mansfield and Lexington, Ohio.

Circle **456** on inquiry card.

Dial Thermometer New 4-page Bulletin 350 describes maker's "Direct Drive" dial thermometer featuring case of stainless-steel, compensation for ambient temperature, and rotation to any readable position.—Palmer Thermometers, Inc., 2501 Norwood Ave., Cincinnati 12, Ohio.

Circle **457** on inquiry card.

Thermocouple Elements. New 4-page Bulletin 14-15-54 describes and illustrates maker's line of "Serv-Rite" thermocouple elements and bare thermocouple wire.—Claud S. Gordon Co., 3000 S. Wallace St., Chicago 16, Ill.

Circle **458** on inquiry card.

Temperature Control. New 2-page Bulletin F-6476 describes and illustrates maker's "Model 297 Capacitrols" that provide accurate "straight line" control required by new plastic machines, methods and materials.—Wheelco Instruments Div., Barber-Colman Co., Rockford, Ill.

Circle **459** on inquiry card.

Subminiature Thermal Switch. New 2-page bulletin describes maker's "MiniTherm" subminiature thermal switch which permits direct operation of solenoid valves, small motors, actuators, or other power devices without intermediate amplification.—MiniTec, 5423 Delaware Ave., Los Angeles 41, Calif.

Circle **460** on inquiry card.

Temperature Control. New 2-page Bulletin 104 describes maker's line of temperature controls featuring expansion-type switch, and including "Model D-1S" for controlling temperatures up to 1800 F.—Burling Instrument Co., Inc., 16 River Rd., Chatham, N. J.

Circle **461** on inquiry card.

Furnaces, Incubators. New 4-page bulletin "Prescription for Your Constant Temperature Problems" discusses oven and furnace problems and solutions.—Electric Hotpack Co., Inc., Cottman Ave. at Melrose St., Phila. 25, Pa.

Circle **462** on inquiry card.

Thermometers, Microscopes, Testers. New 16-page brochure lists distributor's line of "Pandux" pipe surface thermometers used to obtain temperature of pipe and tubes, foam- and sponge-rubber hardness tester, industrial microscopes, etc.—American Industrial & Scientific Co., 11838 A. Pico Blvd., Los Angeles 64, Calif.

Circle **463** on inquiry card.

PRESSURE

Bantam Draft Pressure Gages. New 4-page Brochure 805 describes and illustrates maker's new "V5" bantam gages for measuring draft, pressure, and differential pressure.—Republic Flow Meters Co., 2240 Diversey Parkway, Chicago 47, Ill.

Circle **464** on inquiry card.

Pressure Transmitter. New 2-page Bulletin A-713 describes and illustrates maker's new flush-diaphragm pressure transmitter "Type P3T." Gives principles of operation and dimensions.—Swartwout Co., 18511 Euclid Ave., Cleveland 12, Ohio.

Circle **465** on inquiry card.

Portable Pressure Calibrator. New 4-page Bulletin 52-3 describes maker's portable low-pressure calibrator for testing and calibrating instruments operating at pressures ranging from 0-20 inches water, vacuum, pressure or compound.—Republic Flow Meters Co., 2240 Diversey Parkway, Chicago 47, Ill.

Circle **466** on inquiry card.

Pressure, Flow Calibrator. New 2-page Bulletin 53-3 describes maker's medium-pressure calibrator for fast testing and calibration of pressure instruments operating between 20 inches H_2O and 25 psi.—Republic Flow Meters Co., 2240 Diversey Parkway, Chicago 47, Ill.

Circle **467** on inquiry card.

Pressure Gage. New 4-page Bulletin 1787 describes maker's Bourdon-actuated pressure gage for accurate trouble-free pressure reading.—Designers For Industry, 4746 W. Washington Blvd., Los Angeles 16, Calif.

Circle **468** on inquiry card.

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Vibrotron Pressure Gage. New 6-page folder describes maker's "Vibrotron," variable-frequency pressure gage featuring vibrating-wire sensing element.—Byron Jackson Co., Electronics Div., P. O. Box 2017, Terminal Annex, Los Angeles 54, Calif.

Circle **469** on inquiry card.

Recording Balance. New 4-page Bulletin 103 describes maker's servo-type recording balance for observation of small, rapidly-changing forces applied to moving system.—Sharples Corporation Research Laboratories, 424 W. 4th St., Bridgeport, Pa.

Circle **470** on inquiry card.

Pressure Transmitter. New 6-page Bulletin 5410 describes and illustrates maker's "Type 158 Teledyne" electrical pressure transmitter (strain-gage-type) for telemetering dynamic pressures in ranges from 100 to 10,000 psi.—Taber Instrument Corp., 111 Goundry St., N. Tonawanda, N. Y.

Circle **471** on inquiry card.

WEIGHT

Scales. New 28-page Catalog 11-A presents maker's line of standard scales, including specifications and spot illustrations of dial, counting, weighing and portable scales.—Howe Scale Co., Rutland, Vermont.

Circle **472** on inquiry card.

Weight Recorder. New 4-page Leaflet 681 describes maker's "Teleprint" electronic remote weight recorder for accurate, efficient weight control.—Howe Scale Co., Rutland, Vermont.

Circle **473** on inquiry card.

Weighing Scale. New 4-page Leaflet W-009 describes and illustrates maker's electric weighing scale for either batch weighing or continuous-process control utilizing strain-gage load cells.—Weighing Components, Inc., 64 Fulmor Ave., Hatboro, Pa.

Circle **474** on inquiry card.

Frictionless Hook Scale. New 2-page Bulletin M-25 describes maker's "SU-20 Sensater" friction-free, hydraulic hook scale made in models with capacities up to 20,000 lbs.—Martin-Decker Corp., Long Beach, Calif.

Circle **475** on inquiry card.

FLOW

Proportioning Systems. New 8-page Catalog RP-2000 describes maker's continuous gravimetric proportioning systems. Includes diagrams, photographs, flowgrams and information on electronic load cells, belt-type gravimetric feeders, etc.—Proportioneers, Inc., 345 Harris Ave., Providence, R. I.

Circle **476** on inquiry card.

Flow Regulator. New 2-page bulletin describes and illustrates maker's flow regulator with automatic by-pass for any system requiring a constant-flow rate less than pump output.—Waterman Engineering Co., 721 Custer Ave., Evanston, Ill.

Circle **477** on inquiry card.

Chemical Feeders, Compressed-air Systems. New 4-page issue of "Ratonews" features articles on compressed air survey and on chemical feeders.—Fischer & Porter Co., Hatboro, Pa.

Circle **478** on inquiry card.

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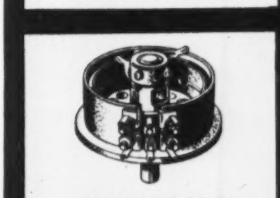

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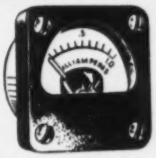
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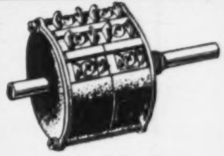
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MANUFACTURERS' NEW LITERATURE

Pumps. New 20-page Brochure RO-103 describes and illustrates maker's aircraft fuel pumps, high-pressure test stand, pressure regulator valves, etc. —Lear, Inc., 3171 S. Bundy Dr., Santa Monica, Calif.

Circle 479 on inquiry card.

Air Meters. New 4-page Bulletin A-7 describes and illustrates maker's compressed air meters which measure air consumption of any pneumatic tool, rock drill, air motor, sand blast, etc.—New Jersey Meter Co., Plainfield, N. J.

Circle 480 on inquiry card.

LEVEL

Digital Remote Tank Gaging. New 4-page Bulletin ES-5 presents description, principles, and specifications of maker's new "Electro-Span" remote tank gaging system for remote electrical measurement of liquid level. Includes features of digital pulse-code system used for interrogation and readout.—Pacific Div., Bendix Aviation Corp., N. Hollywood, Calif.

Circle 481 on inquiry card.

Electronic Level Control. New 4-page Bulletin 253-1 describes maker's "Electro-O-Probe" electronic level switch for liquid-solids, foam, or interface level control. Includes principles of capacitance-type pickup, typical applications, and other instruments offered.—Instruments, Inc., 122 N. Madison, Tulsa, Okla.

Circle 482 on inquiry card.

Level Control. New 2-page Leaflet CP2 describes maker's capacitance-probe-type level control. Includes equipment useful in handling of most non-adhesive chemicals, milk, oils, refrigerants and condensed gases.—Thermo Instruments Co., 1310 County Rd., Belmont, Calif.

Circle 483 on inquiry card.

Ring Balance Meter. New 4-page Bulletin MSA-109 describes maker's ring balance meter for controlling level in high-pressure hydraulic presses of 2000 psi. and upwards.—Hagan Corp., 323 Fourth Ave., Pgh. 22, Pa.

Circle 484 on inquiry card.

Null-Balance Receivers. New 4-page Brochure P-597 describes maker's null-balance receivers for accurate determination of liquid levels in electronic tank gages.—Gilbert & Barker Mfg. Co., W. Springfield, Mass.

Circle 485 on inquiry card.

Tank Gage. New 8-page Bulletin P-591 describes and illustrates maker's electronic tank gage which gives accurate liquid-level gaging in tanks of all sizes, containing any liquid.—Gilbert & Barker Mfg. Co., W. Springfield, Mass.

Circle 486 on inquiry card.

GAGING

Gage Blocks. New 19-page catalog featuring maker's complete line of gage block sets, sine bars, tri-squares, and accessory set, ring, snap and plug gages.—Jansson Gage Co., 13550 Auburn, Detroit 39, Mich.

Circle 487 on inquiry card.

Height Gage. New 6-page leaflet describes maker's height gage giving accurate measurements in production of tools, jigs, fixtures, machine parts and other mechanical devices.—George Scherr Co., Inc., 200 Lafayette St., New York 12, N. Y.

Circle 488 on inquiry card.

HARDNESS, TENSILE

Hardness Tester. New 4-page Bulletin A-12 describes maker's "Wolpert-Gries" machine for standard rockwell hardness tests at a rate of up to 400 tests per hour.—Gries Industries, Inc., Testing Machines Div., Beechwood Ave. at Second St., New Rochelle 6, N. Y.

Circle 489 on inquiry card.

Hardness Tester. New 4-page booklet describes maker's portable "Brinell" hardness tester for rolling mills, foundries, etc.—Andrew King, 67 E. Lancaster Ave., Ardmore, Pa.

Circle 490 on inquiry card.

Paper, Plastic Testing Instruments. New 24-page Bulletin 1400 describes procedures for testing paper stocks, textiles, leather, plastics and other sheet materials. Includes procedures for stiffness, smoothness, porosity, and softness.—W. & L. E. Gurley, Troy, N. Y.

Circle 491 on inquiry card.

Hardness Tester. New 4-page bulletin describes and illustrates maker's "Kentrall" hardness tester adaptable to the use of normal accessories such as goose-neck adapters for internal testing and large diameter penetrators for testing of soft materials.—Torsion Balance Co., Clifton, N. J.

Circle 492 on inquiry card.

Tensile-Testing Machine. New 4-page Bulletin C.T. 1-5 describes maker's motor-driven, hydraulic tensile-testing machine.—Cal-Testing Machine Co., Los Angeles 34, Calif.

Circle 493 on inquiry card.

ENVIRONMENTAL TEST

Environmental Test Equipment. New 12-page Bulletin 754 describes maker's line of environmental equipment which includes "T-Series" units for shrink fitting, low temperature treatment and cold processing of metals.—Bowser Technical Refrigeration, Terryville, Conn.

Circle 494 on inquiry card.

Environmental Test Equipment. New 6-page Catalog 55 describes and illustrates maker's complete line of environmental test equipment. Includes calibration test stand for sensitive calibration of temperature measurement and control devices.—American Research Corp., 11 Brook St., Bristol, Conn.

Circle 495 on inquiry card.

RECORDING

Null-balance Recording. New 43-page Brochure ND46 is basic text on "Speedomax"-type null-balance recording instruments, including principles of potentiometer and bridge circuits, amplifiers, response times, and auxiliaries. Amplifiers described include general-purpose, high-impedance, low-level, current-balance and alternating-current amplifiers.—Leeds & Northrup, 4907 Stenton Ave., Phila. 44, Pa.

Circle **496** on inquiry card.

Data Recording Cameras. New 40-page Catalog describes and illustrates maker's high-speed and data recording cameras for military and industrial use. Includes applications and users of Traid and Automax cameras. —Traid Corp., 4515 Sepulveda Blvd., Sherman Oaks, Calif.

Circle **497** on inquiry card.

Oscillography, Strain Gages, Analytical Instruments. New 16-page issue of "CEC Recordings" (Vol. 8, No. 3) features articles on strain gages—selection, theory and application techniques; analytical services; and oscillogram processor which eliminates darkroom developing.—Consolidated Engineering Corp., 300 N. Sierra Madre Villa, Pasadena 15, Calif.

Circle **498** on inquiry card.

Direct-writing Oscillograph. New 8-page booklet describes and illustrates maker's "Type M Dynograph Recorder" direct-writing oscillograph. Includes specifications and principles and shows variety of sensing elements that can be used with chopper type d-c. amplifier.—Offner Electronics, Inc., Dept. M, 5320 N. Kedzie Ave., Chicago 25, Ill.

Circle **499** on inquiry card.

20-kc. Carrier Amplifier. New 2-page Brochure CEC1550A illustrates and describes maker's Type 1-127 carrier amplifier system, a 4-channel amplifier for signals of 0-3000 cps. Can be used with companion galvanometer.—Consolidated Engineering Corp., 300 N. Sierra Madre Villa, Pasadena 15, Calif.

Circle **500** on inquiry card.

Magnetic Tape Recording. New 9-page Bulletin 54-D describes maker's magnetic-tape data recording equipment for computer, process and machine tool control, and automation applications.—Davies Laboratories, Inc., 4705 Queensbury Rd., Riverdale, Md.

Circle **501** on inquiry card.

Galvanometer Amplifier, Force Pickup. Two new 2-page data sheets describe maker's "Model 2609" galvanometer amplifier for oscillography or tape recording. Also "Model 2101" dynamic force pickup used in investigation of forced vibration in complex structures.—Endevco Corp., 689 S. Fair Oaks Ave., Pasadena, Calif.

Circle **502** on inquiry card.

Receiver Recorder. New 12-page Brochure E12-5 describes maker's recorder for pneumatic and electric transmission systems, including operation and specifications.—Bailey Meter Co., 1050 Ivanhoe Rd., Cleveland 10, Ohio.

Circle **503** on inquiry card.

Sweeping-Image Recorder. New 4-page Brochure 168-754 includes illustrations of research pictures taken with synchronized streak camera. Also discusses optics, interpretation of

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NEW LITERATURE

images, etc.—Beckman & Whitley, Inc., 1096 E. San Carlos Ave., San Carlos, Calif.

Circle **504** on inquiry card.

Electrosensitive-paper Power Unit. New 2-page bulletin describes and illustrates maker's "Electrex" power unit for use with electrically-responsive charting papers.—Gorrell & Gorrell, Haworth, N. J.

Circle **505** on inquiry card.

Tape Recorders. New 4-page Bulletin AB3-1-4 describes maker's line of two- and three-channel audio tape recorders for stereophonic sound and parallel recording.—Ampex Corp., 934 Charter St., Redwood City, Calif.

Circle **506** on inquiry card.

Data Display. New 4-page Bulletin 1001 illustrates maker's indicators for data display and transfer which utilize a conventional electrical circuit as its means of alphanumeric display and transmission.—Union Switch & Signal, Pittsburgh 18, Pa.

Circle **507** on inquiry card.

Graphic Recorder. New 2-page Bulletin BR 100 describes maker's servo-type graphic recorder "Series H C 100" for research and testing applications.—Hazatrol Corp., 215 Market St., San Francisco, Calif.

Circle **508** on inquiry card.

RADIOACTIVITY

Radioactivity Cells. New 10-page Bulletin 105 describes and illustrates maker's Ohmart cells for direct conversion of radioactive energy to electrical energy. Also includes data sheet for interface, level, and specific gravity control applications.—Ohmart Corp., 2236 Bogen St., Cincinnati 14, Ohio.

Circle **509** on inquiry card.

Count Rate Meter. New 2-page data sheet describes Atomlab "Model AT-1" dual timer and "Model A-14" count rate meter which gives continuous meter indication of radioactivity rate of count.—Atomic Center, 489 Fifth Ave., New York 17, N. Y.

Circle **510** on inquiry card.

OPTICS, PHOTOMETRY

Industrial Periscopes. New 4-page Bulletin 301 describes maker's industrial periscopes for viewing inaccessible or dangerous areas.—Kollmorgen Optical Corp., 30 Church St., New York 7, N. Y.

Circle **511** on inquiry card.

Transits. New 16-page Booklet A, "Adjustment of Gurley Transits," describes maker's new cross-section transit, vertical circle verniers, two-vernier vertical circle, methods for making crosswires appear in center of field of view, balancing compass needle.—W. & L. E. Gurley, Troy, N. Y.

Circle **512** on inquiry card.

Monochromatic Illuminator. New 4-page Bulletin 811 describes maker's ultraviolet monochromatic illuminator designed for monochromatic illumination at wavelength between 220 and 440 millimicrons in ultraviolet range; used with microscopes, colorimeters, photometers; for transmission, absorption, emission, radiation, fluorescence, etc.—Farrand Optical Co., Inc., Bronx Blvd. & E. 238th St., N. Y. 70, N. Y.

Circle **513** on inquiry card.

Closed-circuit TV. New 4-page Brochure 3R2436 describes application of "TV Eye" closed-circuit television.—RCA, Engineering Prods. Div., Camden, N. J.

Circle **514** on inquiry card.

Precision Optics. New 6-page Bulletin SC-354 illustrates and describes maker's optical instruments which include microscopes, magnifier, medical spectacles, etc.—Testa Mfg. Co., 10130 E. Rush St., El Monte, Calif.

Circle **515** on inquiry card.

Microscopes. New 2-page Bulletin A-145 describes maker's "Model A" microscope for nature study and industrial work. Includes optical data, instructions, and prices.—Testa Mfg. Co., 10130 E. Rush St., El Monte, Calif.

Circle **516** on inquiry card.

Microscope Illuminator. New 2-page bulletin describes maker's "K-10" microscope illuminator with wide-band light intensity control for all standard microscopes.—Vistamatic Corp., 363 S. Antonio Rd., Los Altos, Calif.

Circle **517** on inquiry card.

Smoke Photometer. New 8-page Bulletin JM-1000-A describes maker's

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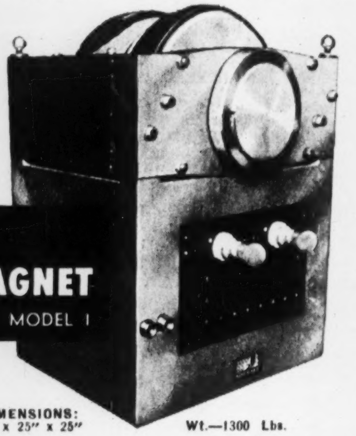

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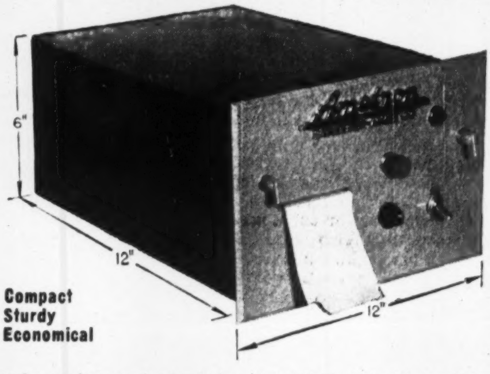

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forward-scattering aerosol and smoke photometer for control applications and air pollution studies.—Phoenix Precision Instrument Co., 3803-05 N. Fifth St., Phila. 40, Pa.

Circle **518** on inquiry card.

ANALYTICAL

Gas Analyzers. New 20-page Brochure 0703-3 describes maker's complete line of combustible-gas analyzers and alarms. Includes principles and operation of bridges, filament circuits, analyzer systems, etc.—Mine Safety Appliances Co., 201 N. Braddock Ave., Pgh. 8, Pa.

Circle **519** on inquiry card.

Chromatographic Equipment. New 24-page catalog describes and illustrates distributor's chromatography equipment—chromatocabs, electrophoresis units, ionographs, absorbents, solvents, fraction collectors, densitometers, colorimeters, and spectrophotometers.—Will Corp., Rochester 3, N. Y.

Circle **520** on inquiry card.

Direct-reading Spectrometer. New 2-page Data Sheet DR-8-54 describes and illustrates maker's "Atomcounter" direct-reading spectrometer for rapid (less than a minute) analyses.—Jarrell-Ash Co., 26 Farwell St., Newtonville, Mass.

Circle **521** on inquiry card.

Gas Analysis Kits. New 2-page Bulletin 306 describes and illustrates "Kwik-Chek" gas analysis kits for rapid on-the-job determination of carbon dioxide or oxygen in flue gases, furnace atmospheres and other gas mixtures.—Burrell Corp., 2223 Fifth Ave., Pgh. 19, Pa.

Circle **522** on inquiry card.

Spectrographic Standards. New 2-page "News Letter" (Vol. 1, No. 3) features articles on low-alloy steel spectrographic standards, and "Fotomarker" for printing identifying numbers on photographic materials.—Jarrell-Ash Co., 26 Farwell St., Newtonville, Mass.

Circle **523** on inquiry card.

Microspectrophotometer. New 2-page Data Sheet M-8-54 describes and illustrates maker's double-beam microspectrophotometer for use with micro quantities of a solution.—Jarrell-Ash Co., 26 Farwell St., Newtonville, Mass.

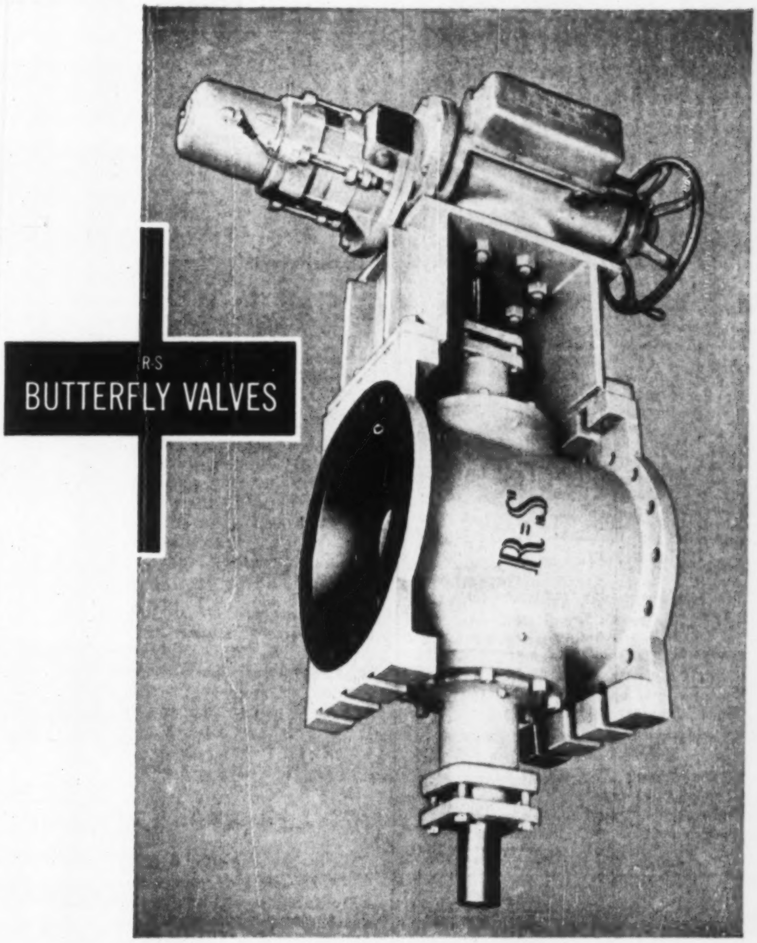
Circle **524** on inquiry card.

Gas Analysis. New 2-page Bulletin 703-A describes maker's combustion-gas sampling system "A-2992" for removing condensate and solids, transporting sample to instrument, and provide for introduction of standardization gases.—Arnold O. Beckman, Inc., 1020 Mission St., S. Pasadena, Calif.

Circle **525** on inquiry card.

Amperometric Titration Cell. New 2-page Data Sheet 11285 describes maker's "Precision-Shell" amperometric titration cell. Includes applications and advantages when used with a polarographic instrument for analytical investigations.—Precision Scientific Co., 3737 W. Cortland St., Chicago 47, Ill.

Circle **526** on inquiry card.



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2.—a	9.—a	16.—a
3.—b	10.—d	17.—b
4.—d	11.—d	18.—a
5.—a	12.—a	19.—d
6.—c	13.—a	20.—a
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NEW LITERATURE

X-ray Diffraction. New 16-page (Vol. 1, No. 7) issue of "Norelco Reporter" features articles on X-ray spectroscopic determination of columbium and tantalum in rare-earth ores, use of acacia in preparing powdered specimens for X-ray diffractometer, etc.—North American Philips Co., Inc., Mount Vernon, N. Y.

Circle **527** on inquiry card.

Distillation Wattmeter. New 2-page Data Sheet 11470 describes maker's "Visi-Watt" for use as accessories on either single or multiple unit "Front-View" distillation units for testing of petroleum products.—Precision Scientific Co., 3737 W. Cortland St., Chicago 47, Ill.

Circle **528** on inquiry card.

Spectrograph. New 8-page Catalog EB-10-54 describes maker's plane-grating spectrograph with order sorter which provides wide wavelength coverage and good speed at high dispersion and resolution.—Jarrell-Ash Co., 26 Farwell St., Newtonville, Mass.

Circle **529** on inquiry card.

Hydrometers. New 10-page Circular 555 gives information on design, construction and calibration of hydrometers and specifies NBS requirements for their certification. Price 10 cents.—National Bureau of Standards, U. S. Dept. of Commerce, Wash. 25, D. C.

Circle **530** on inquiry card.

LAB APPARATUS

Polyethylene Lab Ware. New 8-page Catalog A954 describes maker's polyethylene laboratory ware, including dimensions and prices.—Palo Laboratory Supplies, Inc., 81 Reade St., N. Y. 7, N. Y.

Circle **531** on inquiry card.

Laboratory Supplies. New 8-page issue of "The Palo Retort" presents line of magnifying units, non-sparking stirrer, "Flexistur" paddle for narrow mouth flasks, electric steam generators, etc.—Palo Laboratory Supplies, Inc., 81 Reade St., New York 7, N. Y.

Circle **532** on inquiry card.

Lab Glassware. New 4-page bulletin describes and illustrates maker's distilling apparatus, manometers, condensers, vacuum pumps, etc.—Glass Instruments, Inc., 301 Pasadena Ave., S. Pasadena, Calif.

Circle **533** on inquiry card.

Laboratory Equipment. Nine new 2-page data sheets include description, specifications and technical data on maker's semi-automatic weighing machine, electrical balances, exposure meters, micro manipulators, and paper electrophoresis equipment.—Brinkmann Instruments, Inc., 378-380 Great Neck Rd., Great Neck, L. I., N. Y.

Circle **534** on inquiry card.

3-Speed Stirrer. New 2-page Bulletin 490 describes maker's 3-speed stirrer with speeds of 500, 750, and 1000 rpm.—Eberbach Corp., Ann Arbor, Mich.

Circle **535** on inquiry card.

Laboratory Carts. New 12-page illustrated Folder C2 9/54 describes maker's special purpose carts and portable tables used in industrial laboratories.—Laboratory Construction Co., 1115 Holmes St., Kansas City, Mo.

Circle **536** on inquiry card.

Laboratory Equipment. New 8-page booklet describes and illustrates maker's wide selection of economical standardized laboratory equipment.—Laboratory Furniture Co., Inc., Mineola, N. Y.

Circle **537** on inquiry card.

Centrifuge. New 2-page data sheet describes maker's "Electrifuge Hematocrit Model 30" centrifuge with speed of 11,000 rpm.—C.S. & E. Div., Labline, Inc., 217-221 N. Des Plaines St., Chicago 6, Ill.

Circle **538** on inquiry card.

Laboratory Equipment. New 4-page Bulletin CB-5-54 "Laboratory News" describes and illustrates maker's line of scientific and industrial equipment including microtomes, microscopes, etc.—C. A. Brinkmann & Co., P. O. Box 532, Great Neck, L. I., New York.

Circle **539** on inquiry card.

HUMIDITY, VISCOSITY

Hygrometers. New 4-page brochure describes maker's indicating hygrometer "Type HGS-HY-1", microhygrograph, and hygrothermograph for indoor or outdoor use.—Serdex, Inc., 91 Cambridge St., Boston 14, Mass.

Circle **540** on inquiry card.

Viscometer. New 8-page brochure describes and illustrates application of maker's rotating-spindle-type viscometers for laboratory, plant, and quality control.—Drage Products, Inc., 406 32nd St., Union City, N. J.

Circle **541** on inquiry card.

COMPUTING, DATA CONVERSION

Analog Computers. New 24-page catalog presents principles, features, and operation of maker's new "MC-400" small desk-side-size analog computer, including typical setups and solutions for process and design problems. New 4-page brochure presents auxiliary "MC-600" 6-channel electronic function generator. New 4-page booklet presents "MC-500" analog computer with 30 stabilized amolifiers. New 4-page brochure presents "MC-300" 6-channel recorder for use with analog computers.—Mid-Century Instrumatic Corp., 611 Broadway, New York 12, N. Y.

Circle **542** on inquiry card.

Digital Converter. New 4-page booklet describes maker's digital converter for converting shaft position to digital notation or as an output device for shaft positioning.—Norden Labs. Corp., Milford, Conn.

Circle **543** on inquiry card.

Angular-data Transmitter. New 4-page folder describes maker's new "Inductosyn" data transmission device having maximum errors of 5 seconds of arc.—Farrand Optical Co., Inc., Bronx Blvd. & East 238th St., New York 70, N. Y.

Circle **544** on inquiry card.

COUNTING, TIMING

Counters. New 8-page bulletin describes and illustrates maker's counters which counts up to 99,999 for use on proof presses, shears, sheeting machines, etc.—F. B. Redington Co., 112 S. Sangamon St., Chicago 7, Ill.

Circle **545** on inquiry card.

Frequency Counter. New 2-page bulletin describes and illustrates maker's "DS-6100" electronic frequency counter which counts and displays electrical or mechanical events that can be converted to electrical impulses, from 10 to 100,000 events per second.—Detectron Corp., 5420 Vineland Ave., North Hollywood, Calif.

Circle **546** on inquiry card.

Stopwatches, Blueprint Scaler. New 12-page Catalog 254 presents maker's precision timing instruments including "Minerva" time pieces, "Curvimeter" for scaling blueprints, and "Stop-Watch-Man" for holding a stop watch in action.—M. Ducommun Co., 580 Fifth Ave., New York 36, N. Y.

Circle **547** on inquiry card.

Electronic Timer. New 4-page bulletin describes and illustrates maker's electronic timer for interval timing and timed delay on applications such as induction heating, machine-tool control, etc.—Ferrara, Inc., 8106 W. Nine Mile Rd., Oak Park 37, Mich.

Circle **548** on inquiry card.

Electronic Counter. New 2-page data sheet describes maker's "WE-110" electronic frequency meter and counter that uses glow tubes for measuring angular speed, fuel flow, etc.—Westport Electric, 149 Lomita St., El Segundo, Calif.

Circle **549** on inquiry card.

Dial Timer. New 4-page Bulletin N-80 describes maker's "Duo-Set" timer for controlling on-off cycling of two independently-adjusted load circuits in machine and process control.—Automatic Temperature Control Co., Inc., 5212 Pulaski Ave., Phila. 44, Pa.

Circle **550** on inquiry card.

ELECTRONIC TEST EQUIPMENT

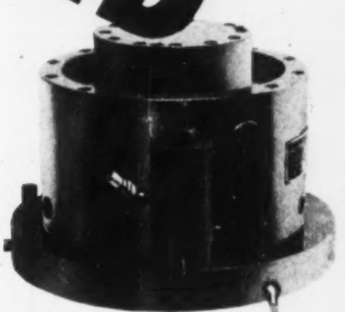
Electronic Test Equipment. New 8-page Form F-671A General Catalog describes and illustrates new imported line of capacitors, capacitance meters, inductance meters, microvoltmeters, oscillators, distortion-factor meters, etc.—Federal Telephone and Radio Co., 100 Kingsland Rd., Clifton, New Jersey.

Circle **551** on inquiry card.

Electronic Test Equipment. New 4-page Booklet FL-9-54 introduces maker's new "Shasta" line of electronic, integrated test equipment—vacuum-tube voltmeters, oscillators, square-wave generators, resistance bridges, power supplies, etc.—Shasta Div., Beckman Instruments, Inc., 1432 Nevin Ave., Richmond, Calif.

Circle **552** on inquiry card.

Spectrum Analyzer. New 4-page brochure describes maker's microwave spectrum analyzers and X-band micro-



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wave analyzer, a unit with vernier-micrometer transmission wavemeter and calibrated input attenuator.—Vectron, Inc., 400 Main St., Waltham 54, Mass.

Circle **553** on inquiry card.

Circuit Analyzer. New 8-page booklet presents description and illustrations of maker's universal, automatic, electrical-circuit analyzer for testing complex electrical systems of modern aircraft.—DIT-MCO, Inc., 505 West Ninth St., Kansas City, Mo.

Circle **554** on inquiry card.

Corona Testing Equipment. New 8-page Bulletin 66-89 describes and illustrates maker's testing equipment including "Model 1" test set consisting of a transformer and control unit used for nondestructive evaluation of electrical insulation.—James G. Biddle Co., 1316 Arch St., Phila. 7, Pa.

Circle **555** on inquiry card.

Signal Generators. New 4-page issue "Hewlett-Packard Journal" (Vol. 5, No. 12) features articles on advanced performance in two new VHF signal generators.—Hewlett-Packard Co., 275 Page Mill Rd., Palo Alto, Calif.

Circle **556** on inquiry card.

Electronic Supplies. New 16-page 1954 fall issue of "This Month" lists complete line of amplifiers, capacitor decades, decibel meters, gages, generators, potentiometers, etc., available from distributor.—Herbach & Rademan, Inc., 1204 Arch St., Phila. 7, Pa.

Circle **557** on inquiry card.

Electronic Equipment. New 12-page Catalog 15 describes and illustrates maker's grid dip meter cathode ray oscilloscopes, absorption wavemeters, r-f. power amplifiers, components, etc. —James Millen Mfg. Co., 150 Exchange St., Malden, Mass.

Circle **558** on inquiry card.

ELECTRICAL, ELECTRONIC INSTRUMENTS

Pulse Generators. New 6-page brochure describes maker's line of unitized pulse control equipment with a frequency range from 15 cycles to 4.5 megacycles.—Burroughs Corp., Electronic Instruments Div., 1209 Vine St., Phila. 7, Pa.

Circle **559** on inquiry card.

Displacement Pickup. New 2-page bulletin describes and illustrates maker's differential transformer amplifier "Model 400" for dynamic study of physical phenomena.—Daytronic Corp., 216 S. Main St., Dayton, Ohio.

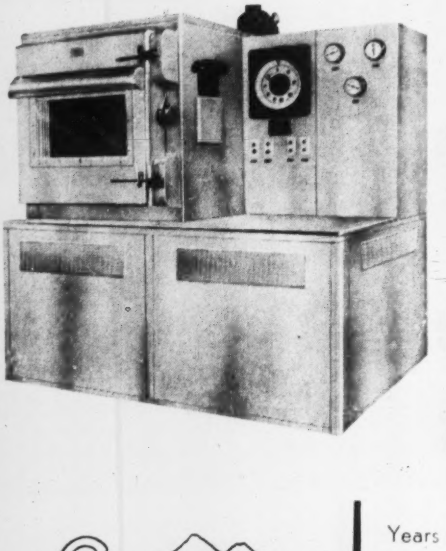
Circle **560** on inquiry card.

Panel Indicators. New 2-page illustrated bulletin describes maker's "Model 152" sealed square panel indicators (milliammeters) for front or rear panel mounting.—DeJur-Amsco Corp., 45-01 Northern Blvd., Long Island City 1, N. Y.

Circle **561** on inquiry card.

RF Heads. New 4-page bulletin presents maker's "25 Series" K-band r-f.

TEST CHAMBERS



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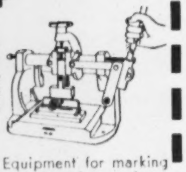

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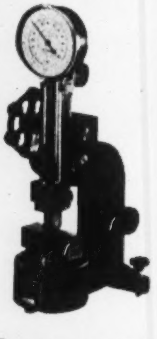

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heads for use with spectrum analyzer. —Vectron, Inc., 400 Main Street, Waltham 54, Mass.

Circle **562** on inquiry card.

Chassis Slide Plates, Handles, Seal nuts. Three new 2-page bulletins describe maker's (1) chassis slide plates for mounting chassis in racks; (2) black vinyl-coated handle with mounting plate; (3) a complete line of "Seal-nuts" for mounting and sealing switches, potentiometers, etc.—Radio Frequency Laboratories, Inc., Boonton 13, N. J.

Circle **563** on inquiry card.

Synchro Alignment Set. New 4-page booklet describes maker's synchro alignment test set for laboratory production testing of electrical zero alignment of synchros and resolvers.—Norden Laboratories Corp., Milford, Conn.

Circle **564** on inquiry card.

POWER SUPPLIES

Converters, Inductor Alternators. New 20-page illustrated Catalog 553 giving complete electrical and mechanical specifications on maker's d-c. to a-c. converters and inductor alternators. Includes selector chart.—Carter Motor Co., 2644 N. Maplewood Ave., Chicago 47, Ill.

Circle **565** on inquiry card.

Power Supplies. New 2-page Data Sheet CEC-1543 presents maker's low-voltage power supply Type 3-132 for 0-15 volts at 0-1 amp.; 2-page Data Sheet 1544PL presents Type 3-122A power supply for 24-v. d-c. application.—Consolidated Engineering Corp., 33 N. Sierra Madre Villa, Pasadena 15, Calif.

Circle **566** on inquiry card.

Dynamotors. New 2-page Bulletin 653A describes maker's "Change-a-volt" dynamotor for 6 volt mobile radio operation. New 4-page Price List 400 (May, 1954) contains models and prices of large line of converters, dynamotors, generators, etc.—Carter Motor Co., 2644 N. Maplewood Ave., Chicago 47, Ill.

Circle **567** on inquiry card.

Selenium Rectifiers. New 8-page Bulletin SR-1A describes and illustrates maker's "Microstak" selenium rectifiers and selenium diodes. Includes construction, applications, types, ratings, reference curves, d-c. characteristics.—International Resistance Co., 401 N. Broad St., Phila. 8, Pa.

Circle **568** on inquiry card.

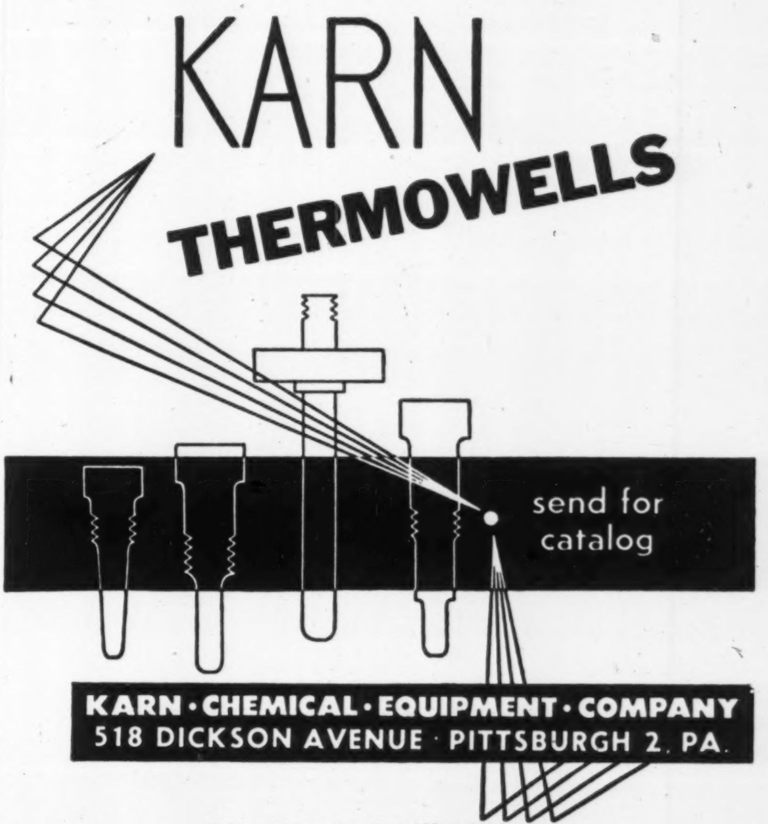
Voltage Stabilizers. New 16-page Catalog 4-260 describes maker's line of line-voltage stabilizers.—Raytheon Mfg. Co., Dept. 6120-PR, Waltham 54, Mass.

Circle **569** on inquiry card.

Power Supply. New 2-page bulletin describes maker's super-precision power supply "Model D3-300-E" which provides regulation for a wide variety of applications involving d-c. voltage. —Dressen-Barnes Corp., 250 N. Vinedo Ave., Pasadena 8, Calif.

Circle **570** on inquiry card.

Electrical Panel. Two new 2-page specification sheets describes maker's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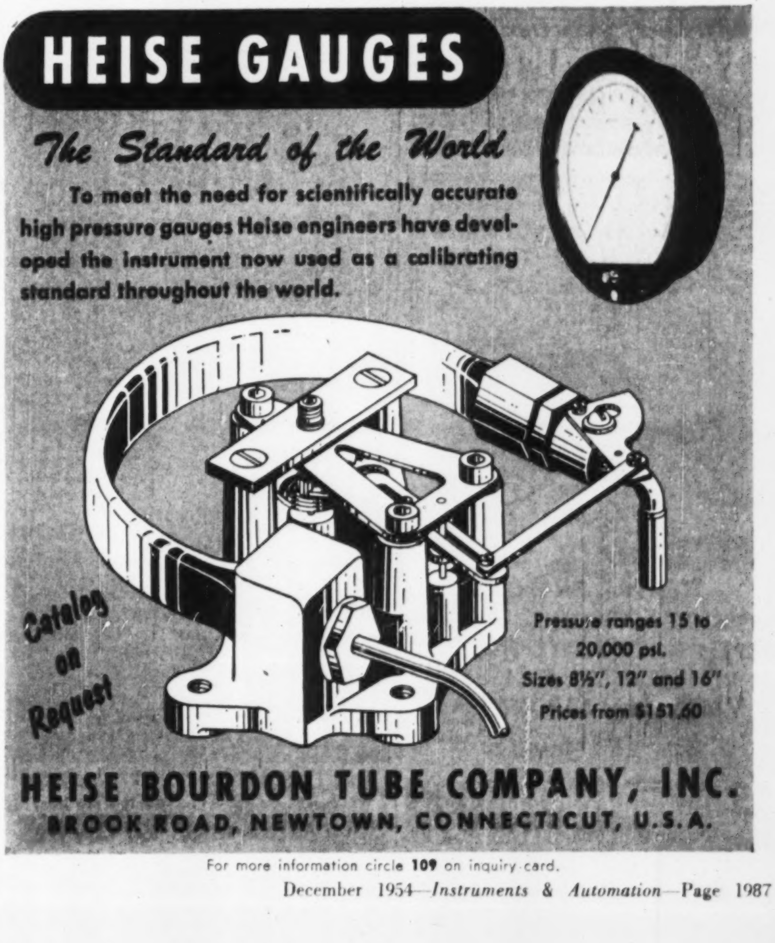
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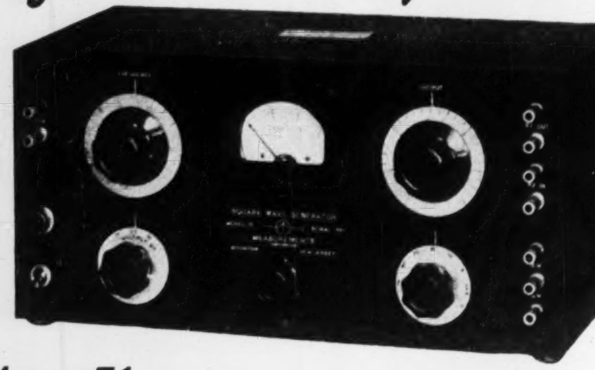

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NEW LITERATURE

"Mellaphone" portable electrical panel for supplying currents and voltages for operating low-voltage devices.—Electronic Rectifier Co., Inc., Rochester 2, N. Y.

Circle **571** on inquiry card.

Voltage Regulator. New 8-page brochure describes maker's "Type 1101" Recostat Generator-Voltage Regulator which consists of stabilizing network, generator-voltage detector, transistor, magnetic amplifier, etc.—Regulator Equipment Corp., Paterson, N. J.

Circle **572** on inquiry card.

Power Supplies. New 8-page Bulletin EB-2 (March 1954) describes and illustrates maker's regulated d-c. power supplies, including laboratory precision and standard, twin units, fixed output and custom designs.—Universal Electronics Co., 2012 South Sepulveda Blvd., Los Angeles 25, Calif.

Circle **573** on inquiry card.

Power Supply. New 2-page Bulletin 10M854 (Vol. 2, No. 4) describes and illustrates maker's power supply for tests requiring an output of 5-500 volts at 0-1 milliampere.—Keithley Instruments, 3868 Carnegie Ave., Cleveland 15, Ohio.

Circle **574** on inquiry card.

Power Supply. New 4-page Booklet 54-4 describes maker's "Model 71" 0-500-volt portable power supply.—Lambda Electronics Corp., 103-02 Northern Blvd., Corona 68, N. Y.

Circle **575** on inquiry card.

DC Power Supplies. New 4-page Bulletin 8000 describes maker's magnetic-amplifier selenium-rectifier regulated d-c. power supplies with ratings from 5 to 50 kw.—Vickers Electric Div. Vickers, Inc., 1815 Locust St., St. Louis 3, Mo.

Circle **576** on inquiry card.

Rectifier Kits. New 2-page price list covers maker's selenium-rectifier kits for from 1.5 ma. at 3700 volts peak inverse to 10 amps at 222 volts peak inverse.—Bradley Labs., Inc., 168 Columbus Ave., New Haven 11, Conn.

Circle **577** on inquiry card.

GRAPHIC CIRCUITS

Printed Circuits. New 8-page bulletin covers maker's terminals, terminal boards, and etched and printed circuits. Illustrates production methods for graphic circuits.—U. S. Engineering Co., 521 Commercial St., Glendale 3, Calif.

Circle **578** on inquiry card.

Printed Circuit Kit. New 4-page Bulletin 3547 describes maker's "S31 Basic Lab Kit" which includes electrically conductive coatings and accessories, shielding paints, magnetic paints, etc.—Micro-Circuits Co., New Buffalo, Mich.

Circle **579** on inquiry card.

Etched Circuits. New 2-page bulletin describes maker's etched circuits, including construction and applications.—Anderson & Sons, Inc., Westfield, Mass.

Circle **580** on inquiry card.

RESISTORS, POTENTIOMETERS

Wire-Wound Resistors. New 32-page catalog describes maker's precision wire-wound resistors. Includes charts and data on various types of hermetically sealed, encapsulated and subminiature resistors.—Daven Co., 191 Central Ave., Newark 4, N. J.
Circle **581** on inquiry card.

Potentiometers. New 2-page Bulletin 4530 describes and illustrates maker's line of miniature linear-motion potentiometers, high-range differential, absolute-pressure potentiometers, etc.—Bourns Laboratories, 6135 Magnolia Ave., Riverside, Calif.
Circle **582** on inquiry card.

Potentiometers. New 4-page leaflet describes and illustrates maker's microfriction potentiometer for remote control and indicating in aircraft, guided missiles, laboratory research, etc. Also includes 2-page data sheet on "Multipot H4" potentiometer.—American British Electric Corp., 57 Park Ave., New York 16, N. Y.
Circle **583** on inquiry card.

Decade Resistors. New 2-page Bulletin RP-854 describes maker's decade resistors "Models RDA, RDB, RDC" for electrical and electronic applications.—Cornell-Dubilier Electric Corp., South Plainfield, N. J.
Circle **584** on inquiry card.

Resistors. New 2-page Bulletin F-3 describes maker's "Type HFR" high-frequency resistors for use in circuitry requiring excellent frequency response over a wide band of frequencies.—International Resistance Co., 401 N. Broad St., Phila. 8, Pa.
Circle **585** on inquiry card.

Hermetically-sealed Resistors. New 2-page Bulletins C1031 and C1034 describe and illustrate hermetically-sealed resistor networks and "PW" resistors (for automation and printing wiring) encapsulated in cast epoxy.—Cinema Engineering Co., 1100 Chestnut St., Burbank, Calif.
Circle **586** on inquiry card.

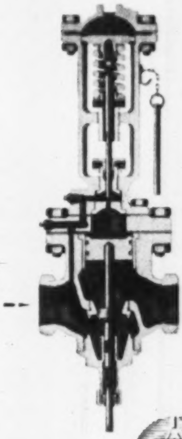
Rheostats. New 2-page issue of "Ohmite News" (Aug.-Sept. '54) describes and illustrates rheostats used for lamp dimming and rheostat tandem coupling kits consisting of a steel "U" frame, mica washer, coupling, Allen wrench and assembly instructions.—Ohmite Mfg. Co., 3603 Howard St., Skokie, Ill.
Circle **587** on inquiry card.

Power Resistors. New 4-page Bulletin 50 describes maker's power resistors, including lug, adjustable, lead, oval, ferrule and made-to-order types.—R. C. L. Mfg. Co., St. Mihiel Drive, Riverside, N. J.
Circle **588** on inquiry card.

RELAYS, SWITCHES

Hermetically-Sealed Relay. New 4-page Bulletin GEA-6211 describes maker's hermetically-sealed, subminiature relay for electronic applications.—General Electric Co., Schenectady 5, N. Y.
Circle **589** on inquiry card.

Time Delay Relays. New 2-page Bulletin TD401 describes maker's



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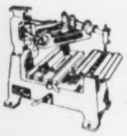

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"Series 6400, 11400, and 24300" adjustable, hermetically-sealed, time-delay relays.—A. W. Haydon Co., Waterbury, Conn.

Circle **590** on inquiry card.

Multipole Switches. New 12-page illustrated Catalog 8054-IN describes and illustrates maker's "Types P and JR" rotary, multipole switches. Includes wiring diagrams and contact charts for voltmeter, ammeter and voltmeter-ammeter switches.—Electro Switch Corp., Weymouth 88, Mass.

Circle **591** on inquiry card.

HF Crossbar Switch. New 2-page bulletin 10MCH454 describes and pictures maker's high-frequency crossbar switch for telephony, telegraphy, inter-communication and computer systems.—James Cunningham Son & Co., Inc., Dept. P., 13 Canal St., Rochester 8, N. Y.

Circle **592** on inquiry card.

ELECTRONIC COMPONENTS

Electronic Supplies. New 196-page Catalog 58 lists thousands of electronic products, components and equipment, including 64-page high-fidelity section, electronic items, augmented industrial equipment and apparatus section.—Newark Electric Co., 223 W. Madison St., Chicago 6, Ill.

Circle **593** on inquiry card.

Germanium-Diode Recovery Time. New 8-page Brochure G2A is treatise on "Recovery Time Measurements of Point-Contact Germanium Diodes." Includes electronic principles, test circuits, and technical discussion.—Hughes Aircraft Co., Semiconductor Div., Culver City, Calif.

Circle **594** on inquiry card.

Plastic Film Capacitors. New 4-page Bulletin 154 describes maker's miniature plastic film capacitors.—Electronic Fabricators, Inc., 682 Broadway, New York 12, N. Y.

Circle **595** on inquiry card.

Capacitors. New 4-page Catalog C-6 describes maker's "Hy-Therm" subminiature, hermetically-sealed capacitors for applications requiring high insulation resistance and stability at high temperature.—Hopkins Engineering Co., 2082 Lincoln Ave., Altadena, Calif.

Circle **596** on inquiry card.

High-voltage Connectors. New 2-page catalog sheet describes maker's "Series 800" precision high-voltage connectors for "AN 36" shell used for critical high-voltage applications.—DeJur-Amsco Corp., 45-01 Northern Blvd., Long Island City 1, N. Y.

Circle **597** on inquiry card.

Variable-ratio Transformer. New 6-page brochure describes new "Vernistat," a precision variable-ratio transformer. Includes performance curves and application in computer and servo systems.—Vernistat Div., Perkin-Elmer Corp., Norwalk, Conn.

Circle **598** on inquiry card.

Current, Potential Transformers. New 1-page Bulletin 2004 describes and illustrates maker's precision multirange current transformer, test set for watthour meters, potential transformer, etc.—Electrical Facilities, Inc., 4224 Holden St., Oakland 8, Calif.

Circle **599** on inquiry card.

Transformers. New 8-page Review 2001-A covers maker's tapping switchboard panel, soldering leads, assembling rectifier equipment, current transformers, reactors coils, etc.—Electrical Facilities, Inc., 4224 Holden St., Oakland 8, Calif.

Circle **600** on inquiry card.

Transformers, Reactors. New 24-page Catalog B describes and illustrates maker's line of transformers, reactors, broadcast and recording equalizers, and filters.—United Transformer Co., 150 Varick St., New York 13, N. Y.

Circle **601** on inquiry card.

Toroid Transformers. New 2-page descriptive bulletin (August 1954) presents description, specifications and uses of maker's "Series STI-ST4" miniature toroid transformers.—Mico Instrument Co., 80 Trowbridge St., Cambridge 38, Mass.

Circle **602** on inquiry card.

Connectors. New 8-page issue of "Amphenol Engineering News" (Vol. 7, No. 6, Nov. 1954) features articles on blue ribbon connectors, tele-couplers, pulse generators, etc.—American Phenolic Corp., 1830 S. 54th Ave., Chicago 50, Ill.

Circle **603** on inquiry card.

PLASTICS, TUBING

Plastic Tubing. Two new 6-page folders describe distributors' "Tygon" flexible plastic tubing which is unaffected by most acids, alkalies, oils, etc. Includes maker's complete line of heating mantles with aluminum housings.—Boder Scientific Co., 719 Liberty Ave., Pgh. 22, Pa.

Circle **604** on inquiry card.

Plastic Pipe. New 6-page Bulletin 80-A describes and illustrates maker's chemical-resistant "Dur-Ace" plastic pipe, fittings and valves for processing industries, farming, and general industrial use.—American Hard Rubber Co., 93 Worth St., New York 13, N. Y.

Circle **605** on inquiry card.

Flexible Plastic. New 2-page bulletin describes maker's "Gravoflex" flexible, shatter proof, stain-resistant plastic which can be sheared, punched, stapled, stamped, etc.—Hermes Plastics, Inc., 13-19 University Place, New York 3, N. Y.

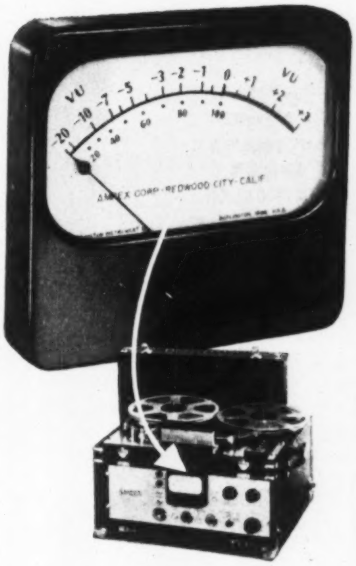
Circle **606** on inquiry card.

Extruded Plastics. New 4-page Bulletin AP 55 RM illustrates variety of shapes, rods, strips, and tubes which can be custom extruded from thermoplastics. Includes general specifications of various types.—Anchor Plastics Co., Inc., 36-36 36th St., Long Island City 6, N. Y.

Circle **607** on inquiry card.

Plastic Tubing. New 6-page bulletin describes "Cobon" polyvinyl-chloride transparent flexible tubing, and "Cobonol" polyethylene plastic tubing.—Couse & Bolten Co., 42-46 Lafayette St., Newark 2, N. J.

Circle **608** on inquiry card.



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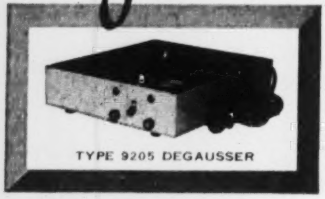
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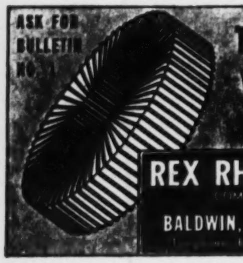

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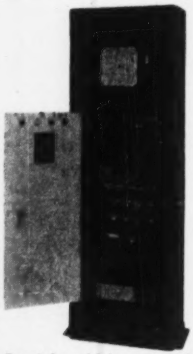

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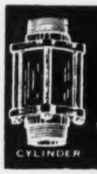
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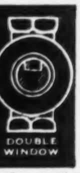
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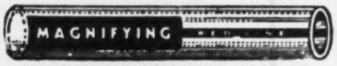

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MAGNETS

Permanent Magnets. New 8-page issue of "Applied Magnetics" (Vol. 2, No. 6) features articles on "Magnetic Domains" and "Will the Permanent Magnet Replace the Mechanical Latch?".—Indiana Steel Products Co., Valparaiso, Indiana.

Circle **609** on inquiry card.

FABRICATION, TOOLS

Fabrication, Assembly Facilities. New 20-page brochure "More Dollars From Less Space" gives suggestions on improving the efficiency of any department, setting up work space, planning a new product, etc.—Alden Research Center, Westboro, Mass.

Circle **610** on inquiry card.

Engraving Machine. New 4-page bulletin describes maker's Model D-2 heavy-duty "Pantograph" engraver for profiling and engraving large panels and bulky work pieces.—Green Instrument Co., 386 Putnam Ave., Cambridge, Mass.

Circle **611** on inquiry card.

Broaching Fixtures. New 12-page Catalog B54-9 describes maker's "Red Ring" self-contained, air-powered bench-type broaching fixtures with power clamping, mechanical indexing and automatic feeding features. Used for keyways, slotting, burring, small splines, oil grooves, etc.—National Broach and Machine Co., 5600 St. Jean, Detroit 13, Michigan.

Circle **612** on inquiry card.

Flexible Conduit, Connectors, Swaging Machines. New loose-leaf bound catalog contains over 150 pages on maker's flexible conduit and fittings, electrical connectors, conduit junction boxes, swaging equipment, tab controls, radio ignition shielding, flexible metal tubing, tachometer and remote control drives and hose clamps.—Breeze Corp., Inc., 41 S. Sixth St., Newark, N. J.

Circle **613** on inquiry card.

Grinding Wheels. New 4-page Brochure A1310 "V40 for Tool Room Grinding" describes maker's line of tool room wheels and lists hints for conservation of tools. Includes chart of recommendations for grinding high-speed tool and die steels.—Carborundum Co., Niagara Falls, N. Y.

Circle **614** on inquiry card.

Brakes. New 16-page manual gives specifications and capacities of maker's "Di-Acro" standard, box finger and radius brakes.—O'Neil-Irwin Mfg. Co., 554 Eighth Ave., Lake City, Minn.

Circle **615** on inquiry card.

Torque Screwdriver. New 2-page bulletin describes and illustrates maker's "Roto-Torq Model PM-5" torque screwdriver designed for electronics and precision assembly production work.—Richmond, Inc., 922 S. Myrtle Ave., Monrovia, Calif.

Circle **616** on inquiry card.

Torque Wrenches. New 20-page catalog describes maker's torque limiting wrenches and accessories.—Jo-Line Tools, Inc., 8442 Otis Street, South Gate, Calif.

Circle **617** on inquiry card.

MATERIALS, COMPONENTS

Precision Parts. New 4-page Brochure 4545MR describes and illustrates maker's automatic screw machines and facilities for screw slotting, close hole drilling, etc.—Specialty Screw Machine Products Co., Dillerville Rd., Lancaster, Pa.

Circle **618** on inquiry card.

Precision Bearings. New 4-page bulletin presents maker's precision jewel bearings, hardness comparison chart, and cross-section blueprints of bushing jewels, ring or balance jewels, etc.—Swiss American Jewel Bearings Co., 32-30 58th St., Woodside 2, L. I., N. Y.

Circle **619** on inquiry card.

Hermetic Seals. New 4-page bulletin describes maker's custom-designed, standard-priced hermetic seals for relays and other components.—Sealtron Corp., Reading Rd. at Amity, Cincinnati 15, Ohio.

Circle **620** on inquiry card.

Utility Desk Assemblies. New 8-page Bulletin C2 describes and illustrates maker's complete line of "Parmetal" utility desk assemblies.—Par-Metal Products Corp., 32-62 49th St., Long Island City 3, N. Y.

Circle **621** on inquiry card.

Vibration Isolators. New 8-page Bulletin 541 describes and features uses of maker's "Type 5200" shock and high-vibration isolators for application in marine, transportation and industrial fields.—Barry Corp., Dept. 541, 1000 Pleasant St., Watertown, Mass.

Circle **622** on inquiry card.

Metal Knobs. New 2-page Bulletin 223 describes and illustrates maker's hand-machined metal knobs for custom-built equipment.—Pacific Transducer Corp., 11921 W. Pico Blvd., Los Angeles 64, Calif.

Circle **623** on inquiry card.

Industrial Porcelains. New 36-page catalog describes maker's high-temperature porcelain protection- and insulating-tubes, porcelain insulators, combustion tubes, crucibles, jars, etc. Includes 14-page price list.—McDanel Refractory Porcelain Co., Beaver Falls, Pa.

Circle **624** on inquiry card.

Flexible Shafting. New 16-page Bulletin 528 describes and illustrates maker's flexible shafting for remote control of valves and equipment.—Stov Mfg. Co., 443 State St., Binghamton, N. Y.

Circle **625** on inquiry card.

Screw-Lock Inserts. Two new 4-page Bulletins 715 and 708 describes and illustrates maker's screw-lock insert of 18-8 stainless-steel wire with an ultimate tensile strength of 200,000 psi.—Heli-Coil Corp., Danbury, Conn.

Circle **626** on inquiry card.

Altitude Nomograms. New 8-page Data Sheet 20201-1 gives nomograms, techniques, and short-cuts to calculating volumes and weights of cooling air required in diverse airborne applications.—Rotron Mfg. Co., Schoonmaker Lane, Woodstock, N. Y.

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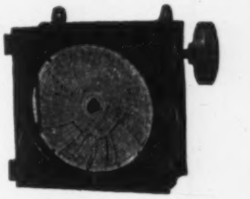

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Important Correction:

In the article "The High-vacuum Standard—The McLeod Gage," by Earl W. Flosforf (*INSTRUMENTS & AUTOMATION*, November, 1954) the type slipped and an error appeared in the table on page 1796. As the entire discussion of the effect of water vapor on the gage reading is based on this table, we are republishing the table on gummed backing so that each reader can paste the corrected table over the incorrect one—and then reread this important article.

Table—Effect of Water Vapor on Untrapped-gage Reading

Known Pressures			*Untrapped-gage Readings**							
			0-500-micron model				0-5000-micron model			
Partial Pressures (microns) due to			Scale distance (mm.) due to			Pressure read (microns)	Scale distance (mm.) due to			Pressure read (microns)
Air	Vapor	Total	Air	Vapor	Total		Air	Vapor	Total	
2	250	252	7	22	29	23	1	22	23	120
100	150	250	51	22	73	200	22	12	34	250**
100	1500	1600	51	22	73	200	22	22	44	450
100	4900	5000	51	22	73	200	22	22	44	450

*With proper trap, vapor is replaced by air so that pressure read in all cases agrees with known total pressure.

**With untrapped gage this reading is the only one agreeing with known total pressure.

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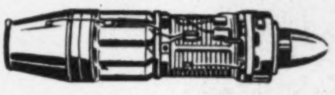
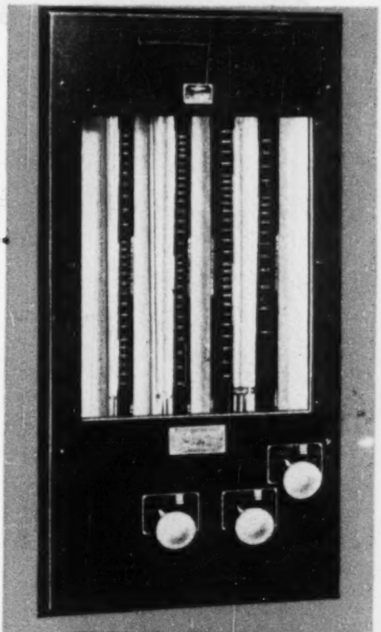


ITS INTRICATE FUEL SYSTEM MUST "***FLOW***"



TYPE 12 - 90 SERIES

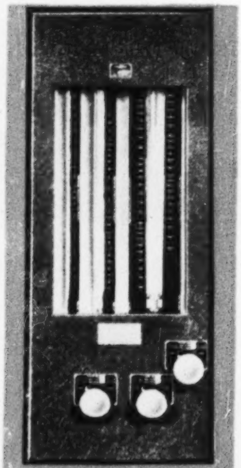
AND THAT MEANS

COX *Multiple Stage type 12* FLOWMETERS

Ever stop to wonder why Cox Multiple Stage Type 12 Flowmeters are so **widely** used by the U. S. Airforce and U. S. Navy?

The answer is that both these services must know *exactly* how much fuel a plane's fuel pumps and fuel nozzles can handle in a given amount of time—in order to determine the operating reliability of its intricate fuel system. In jets, particularly, accurate flow rate testing is essential, since the fuel system must be capable of pumping and carrying tremendous amounts of fuel each minute the plane is in the air.

Experience has shown America's major users of precision flowmeters that the Cox Type 12 can always be depended upon for *first-rate performance*. Its record of service is unmatched in providing accurate, dependable testing of jet nozzles, fuel pumps, carburetors, and other items forming the vital "flow systems" of jet and reciprocating engines.



TYPE 12 - 100 SERIES

The Cox Multiple Stage Type 12 is available in three series—the 40, the 90, and the 100. All possess remarkable accuracy, repeatability and quick response. Maximum capacity of the *40 Series* and the *90 Series* is 36,000 pounds per hour. *The 100 Series* provides a maximum flow capacity of 32,500 pounds per hour. Use of a bypass orifice greatly increases the flow capacity of each instrument without increasing its frontal area.

Readings to the nearest graduation on individually graduated logarithmic type scales are normally within ½% to 1% of the indicated flow, depending on the particular series. Flowmeters are calibrated for a specific fluid and scales for metering liquids of different characteristics can be easily interchanged.

Patented "Inner Wall" guides, integral with the metering tube, assure a true flow pattern by keeping the float centered in the tube at all times.

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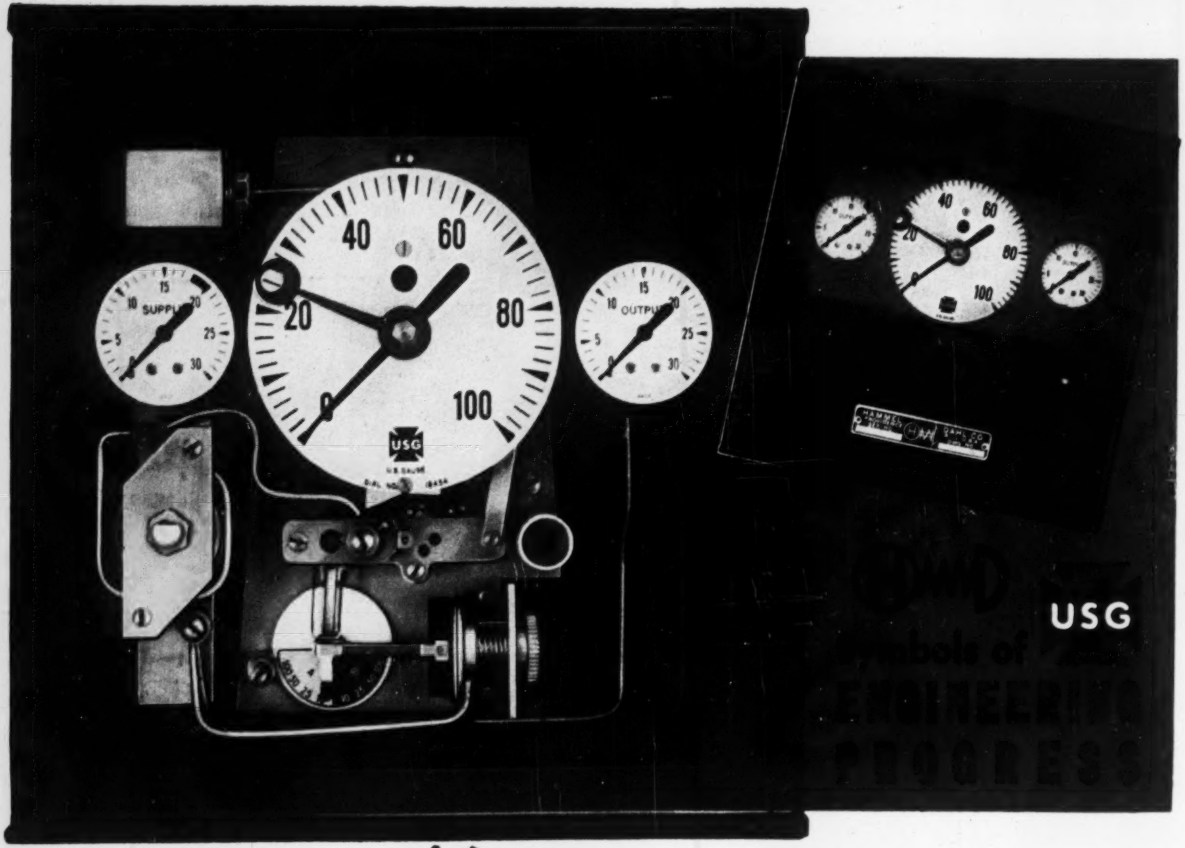

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HANDBOOK of MEASUREMENT and CONTROL

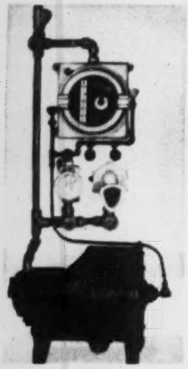
Part Two of
Instruments and AUTOMATION
Vol. 27, No. 12, Dec. 1954

For Accurate DETECTION MEASUREMENT CONTROL

of Industrial Atmospheric Hazards Specify Dependable

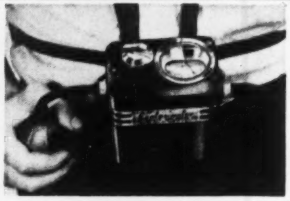
M·S·A INSTRUMENTS

COMBUSTIBLE GASES



M.S.A. Combustible Gas Alarm

This widely-used instrument assures safe, continuous sampling of atmospheres for combustible gases and vapors. Its explosion-proof construction permits installation in hazardous areas. Visual and audible warning when concentrations exceed predetermined percentage of lower explosive limit. The Alarm may be wall mounted, if desired, and can be arranged for multi-point sampling with one instrument. Bulletin No. DT-6.



M.S.A. Explosimeter

Accurate, one-hand operation for detecting and measuring flammable gas hazards and for locating gas leaks. Designed for day-in, day-out use. Compact, light weight, sturdy, easy to use. Meter is calibrated for easy reading. Ask for Bulletin No. DN-7.

M.S.A. Lira

This infra-red gas and liquid analyzer is ideal for measuring atmosphere contamination and for process control. It is extremely accurate, with rapid response to changing concentrations. Designed for permanent installation and continuous recording. Bulletin No. DZ-4.

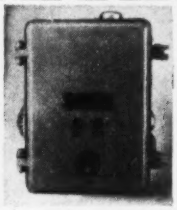
ALSO:

- Combustible Gas Indicators
- Benzol Indicators
- Methane Alarms, Detectors, Recorders
- Oxygen Indicators and Recorders
- Water Vapor Recorder
- Thermal Conductivity Analyzer
- Gascope

TOXIC GASES

M.S.A. Carbon Monoxide Tester

Employing the most advanced colorimetric method of carbon monoxide detection, this accurate instrument will indicate CO in air from 0.001 to 0.10 percent by volume. Simple to use; requires no special training. Accurate in the presence of water and gasoline vapors. Bulletin No. BY-1.



M.S.A. Carbon Monoxide Alarm

Whenever carbon monoxide reaches a predetermined concentration, this precision instrument gives a prompt, loud warning and visible indication. Designed for 24 hour service, the unit is enclosed in a weather-proof case. Bulletin No. DR-2.

M.S.A. Hydrogen Sulfide Detector

Quick detection and accurate measurement of low but dangerous concentrations of hydrogen sulfide in air and process gases. Detects amounts ranging from 0.0025 to 0.04 percent by volume. Supersensitive models available for 0 to 50 p.p.m. Bulletin No. DY-3.

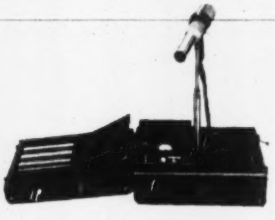
ALSO:

- Carbon Monoxide Detectors, Indicators, Recorders
- Hydrocyanic Acid Gas Detector
- Aromatic Hydrocarbon Detector
- Nitrogen Dioxide Detector
- Samplair (for toxic dust or mist determination)

HARMFUL DUSTS

M.S.A. Midget Impinger

A compact, easy to operate instrument for obtaining accurate samples of particulate matter. Samples at the rate of 1/10 cubic feet per minute. Portable, self-contained, this unit is ideal for dust control and survey work. Bulletin No. CT-6.



M.S.A. Electrostatic Sampler

High efficiency in atmospheric sampling for all types of particulates including dust and fumes from molten metal and smoke. Features a portable head for sampling at various levels. Convenient to carry. Bulletin No. CT-9.

M.S.A. Dust-Vue Microprojector

Permits rapid, easy counting of dust particles in collected samples, and particle size determination. Magnifies to 1000 times in size on ruled translucent screen—relieves eye-strain and permits greater accuracy. Bulletin No. CT-7.

ALSO:

- Dust Counting Microscope
- Cascade Impactor
- Dust Counting Cells
- Smokescope
- Thermal Precipitator
- Settlement Dust Collector

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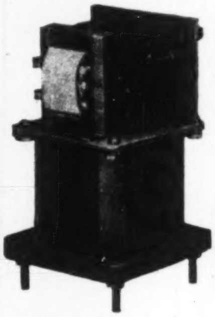

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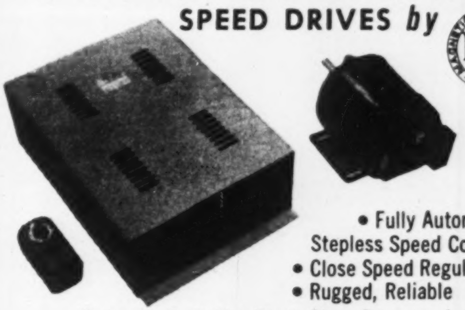

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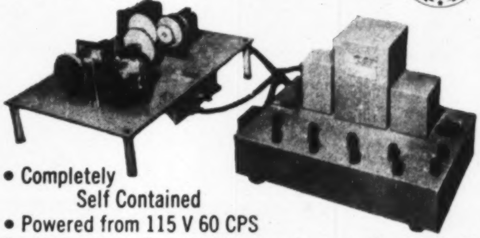

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Features:
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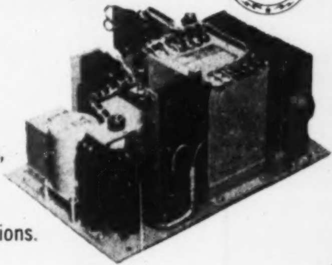

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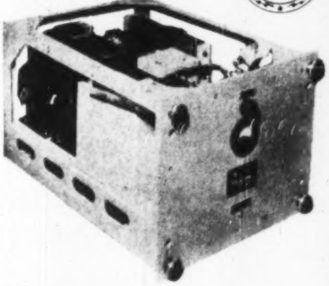
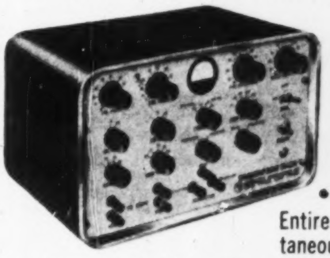


TRANSISTOR CURVE TRACER by MA



- Displays Output or Transfer Curve in Grounded Base or Grounded Emitter
- Dynamically Displays Entire Family of Curves Simtaneously on Oscilloscope
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- Measures PNP or NPN Junction Transistors and P or N Type Point Contact Transistors

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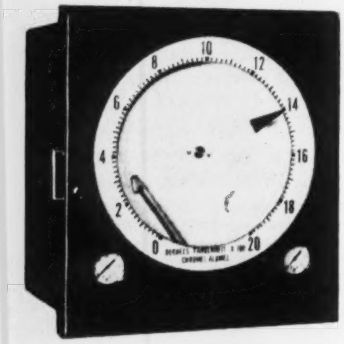
← For more information circle 1 on inquiry card. For more information circle 2 on inquiry card.

FOR ACCURATE MEASUREMENTS

Here are some representative samples of the more popular lines of high-quality electric instruments and associated devices manufactured by General Electric. Whether the field of measurement is plant maintenance, general testing, laboratory service, or power-circuit instrumentation, standard equipment for most applications is available from stock for quick delivery.



RECORDING CONTROLLER

Reduced maintenance is assured by elimination of dry cells, standard cells, slidewire and sliding contacts.

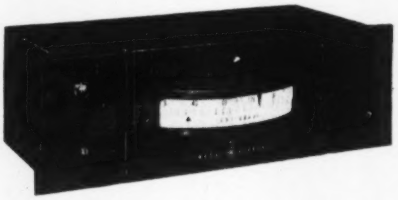
The "Magnetic Standard" provides continuous standardization through the measurement-circuit design, which incorporates high stability of a permanent magnet for a reference standard. Loss of measurement and control during standardization periods are eliminated by the constantly balancing system.

The recording controller offers long term accuracy and precision of measurement; continuous highly dependable control; increased chart visibility; simplified chart changing; and better protection of processes against damage due to component failure. For further information, contact your nearest G-E Apparatus Sales Office or write for Bulletin GED-2100, General Electric Company, Section 640-409, Schenectady 5, N. Y.

PYROMETER CONTROLLER

General Electric pyrometer controllers provide better protection against costly heat damage on the payload of a furnace in three ways. Heat is automatically shut off, when: a thermocouple fails, power to the instrument is disrupted, or the tube burns out or loses emission.

Available in 2-position and 3-position models, these pyrometer indicating controllers offer a variety of ranges in the 0-3000 F span.



MOLECULAR VACUUM GAGE

Similar to "fluid clutch" in principle of operation, it overcomes many of the problems encountered in the use of other type vacuum gages. It has no primary element to burn out, is unharmed when inadvertently opened to atmospheric pressure, is simple to operate, and is highly versatile.

Available in two types, the new G-E molecular vacuum gage is supplied with a scale for the direct reading of dry air or with a linear scale which may be calibrated for other gases. It is therefore suitable for laboratory and research installations. For further information, contact your nearest G-E Apparatus representative or write for Bulletin GEC-986 to General Electric Company, Section 640-409, Schenectady 5, N. Y.

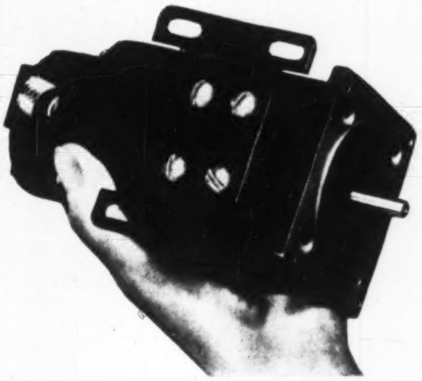
ADDITIONAL INFORMATION AVAILABLE

Bulletin GEC-1016 gives a broad coverage of most of our lines, and various product bulletins give more specific information on each type. They're all available to you if you'll just contact your nearest G-E Sales Office or write to General Electric Company, Section 640-409, Schenectady 5, N. Y.

MEASURING EQUIPMENT

For more information circle 3 on inquiry card.

IN MANY FIELDS G-E INSTRUMENTS



D-c TACHOMETER GENERATOR

Provides a low-cost answer to many speed-measurement and control problems. Designed to occupy a minimum of space, it can be either flange- or foot-mounted, installed horizontally or vertically. This high versatility allows equipment to be direct coupled, geared, or belt driven, as needed.

Available in two different models, it can be supplied with an output voltage up to 100 volts per 1000 rpm, making it ideal for use as a pilot exciter on many control applications.

G-E recording instruments or precision-indicating instruments, such as panel and portable indicators, can be used with the generator to provide highly dependable speed check or records. This is only one of the many generators available on G.E.'s complete line of speed-measuring systems. For further information about General Electric speed-measuring systems, contact your nearest G-E Apparatus Sales Office.

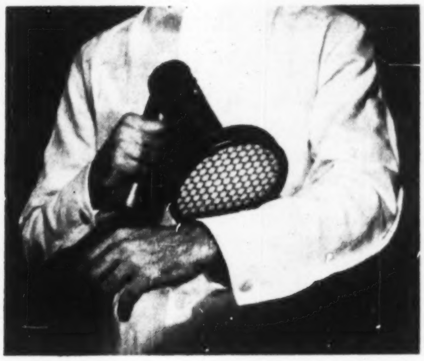
PHOTOELECTRIC RECORDER, TYPE CE

Developed to satisfy the requirements of high sensitivity, low burden, and extremely rapid response, this recorder is especially useful with thermocouples for specialized temperature work, since it obtains accurate records even though the temperature changes rapidly. It can record anything that can be measured with an indicating instrument, and is particularly applicable to electronic circuits because its sensitivity reduces the load imposed on the vacuum tubes.

Some of the forms in which it can be supplied are: d-c galvanometers, millivoltmeters, microammeters, milliammeters, potentiometers, and single-phase wattmeters.

RADIATION INSTRUMENTS

General Electric has a comprehensive line of radiation instruments for use in laboratory research or on the production line. Some of the instruments available are: radiation monitor, scintillation counter, portable radiation probe, area health monitor, air-equivalent ionization chamber, and others. If you have a radiation problem, contact your nearest G-E Apparatus Sales Office.



SCINTILLATION-TYPE ALPHA POPPY

The a-c alpha poppy is an alpha-particle detector using the scintillation principle, designed as a health monitoring device for inspecting clothes, laboratory areas, machines, and benches suspected of alpha contamination. Poppy will operate successfully with most scalers and rate meters. Often used with devices which give an audible "popping" signal.

It has a large sensitive area (150 square centimeters), low background, is insensitive to beta and gamma radiation, and is lightweight, easily handled.

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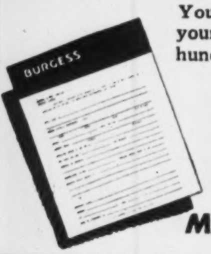

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HANDBOOK OF MEASUREMENT and CONTROL

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PUBLISHER'S FOREWORD

IN recent years the general public has become aware—almost as much as experts—of the rapid growth of Instrumentation—either under its own name or under such names as "Automation," "Cybernetics," "the Second Industrial Revolution," "the Manless Factory," etc. Thus, the rapid growth of the occupational field of Instrumentation has created a demand and a need for a *Handbook of Measurement and Control.*

This *Handbook* is designed to bring classifications, operating principles, and typical applications of instruments to users, manufacturers, and students. The term "instruments" includes indicating, recording, integrating, controlling, and computing devices used in measurement, inspection, testing, analysis, computation, and automatic control applications. Laboratory, scientific, engineering, and industrial instruments are dealt with.

The broad coverage precludes detailed discussion of physical fundamentals of every type. However, all basic methods are covered. The emphasis is on practical factors.

The reader will find the many tables of classifications valuable. It has been said often that a good illustration is worth ten thousand words. The same can be said of each of the many excellent tables which list operating ranges, percent accuracies, recommended practices, etc. Scientists, engineers, application experts, students, teachers, and maintenance personnel will find this book particularly valuable.

Attention is directed to the wealth of background and experience of the authors of this book. The principal contributor, Major M. F. Behar, is the pioneer in this field. Since 1924, when he began to formulate this new science, his contributions have nurtured and accelerated the expansion of the field. Each of the other authors is an expert with long experience in his branch of the field.

Each chapter describes methods but not commercial products. There are no photographs; and the drawings are "schematics" of *types*, not of makes. Therefore, manufacturers were invited to describe their products in advertisements which follow the chapters.

This *Handbook* will be revised, expanded, and republished periodically in the future. The coverage and treatment will be expanded. The Instruments Publishing Company will welcome all comments and suggestions on the *Handbook.* They will be used in a continuous effort to make this Handbook of ever-increasing value to its owners and readers.

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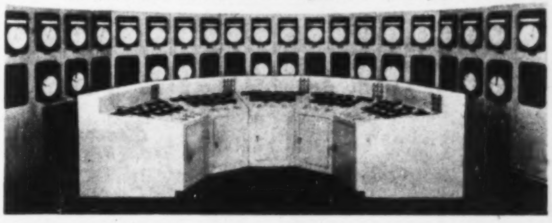

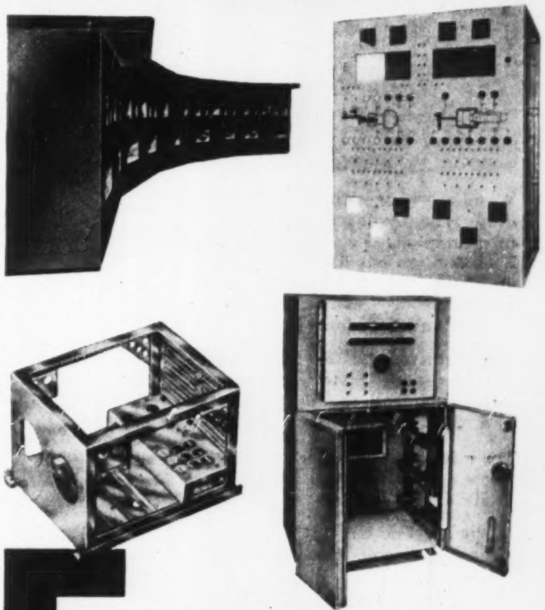

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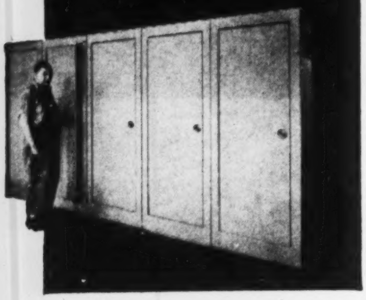

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THE HANDBOOK OF MEASUREMENT and CONTROL

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Editor of *Instruments and Automation*

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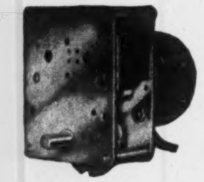
Cramer
TIMING DEVICES

SPECIALISTS IN TIME CONTROL

TYPE IE INTERVAL TIMER

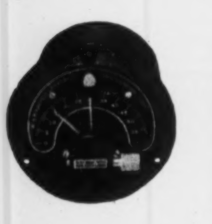
Turning knob to desired time setting starts time cycle. Progress indicated by pointer traveling towards zero. Built-in push button, to initiate timing cycle, available as optional feature.

INTERVAL TIMER TYPE IG



Similar to IE above, but without front plate and housing. Designed for built-in applications, where timer is mounted behind panel and shaft protrudes thru panel. Dial and pointer optional extras.

RESET TIMER TYPE RE

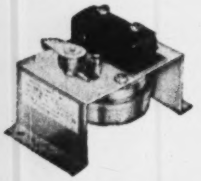


Pressing built-in start button switches circuits and starts timer. Progress indicated by independent pointer traveling towards zero. At end of cycle circuits switch back and timer resets, ready for a new cycle.

TIME DELAY RELAYS TYPES TE — TEC

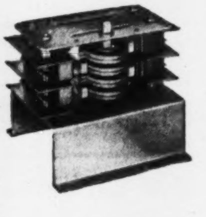
Highest accuracy for precision timing. Timing cycle initiated by external means. Micrometer knob on range pointer for extremely precise setting. Progress pointer indicates time remaining.

TIME DELAY RELAY TYPE TF



For built-in applications. Provides fixed time delay between closing of external contact and switching of load circuits. Enclosed snap-type switch mechanism.

CYCLE TIMER TYPE CF



Permits automatic control of 1 to 8 circuits. Single or multiple cam units permit adjustment to any desired time sequence. May be arranged to stop at the end of one complete cycle or repeat cycle continuously.

PULSE TIMER TYPE V

Repeats electrical impulse of predetermined duration at the end of any desired time interval which may be set upon the dial. Ideal for such applications as automatic lubricators, conveyors, sludge pumps, bar screens, feed water controls, etc.

PERCENTAGE TIMER TYPE PE

Adjustable automatic timer to control percentage of time in which an electrical circuit is closed or open out of a definite time cycle. Ideal to control operating time of an oil burner, furnace, etc.

RUNNING TIME METER TYPE E

An elapsed time indicator to register total operating or idle time of any machine or system. Excellent for indicating usage time of vacuum tubes or machine tool cutter, etc., in conjunction with a preventive maintenance program.

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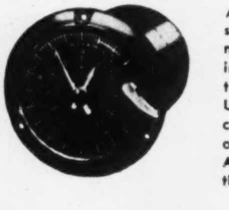

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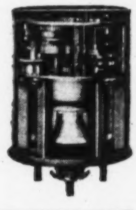
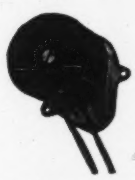
HERMETICALLY SEALED TIME DELAY RELAY TYPE HTI



Retains high accuracy of standard Cramer timers, but is miniaturized for airborne or mobile applications. Hermetically sealed in steel case and tested to meet most rigid military applications.

SYNCHRONOUS TIMING MOTOR



TYPE 112

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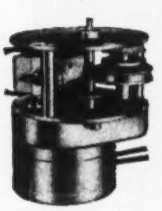

KX motor with differential gear-type clutch. Used where reset is needed or where extremely accurate clutching is required.

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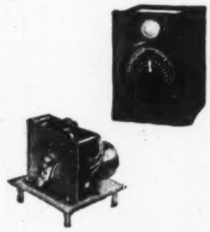

In addition to the standard panel mounting timers illustrated above, Cramer manufactures a complete line of special purpose timers, timers in special enclosures, hermetically sealed devices, etc.

Write for complete information about your timing requirements or for advice on special problems.

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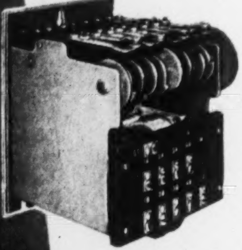

POLYPULSE
Bulletin 330

REPEAT CYCLE

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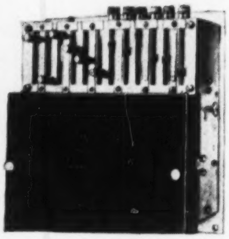

MULTIFLEX
Bulletin 130

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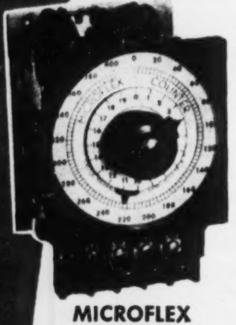
These timers are used where operation of a pilot or control switch starts the timing period. They are spring reset back to their starting position. Timing and resetting are electrically controlled making these timers applicable to automatic processes.



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COUNTER
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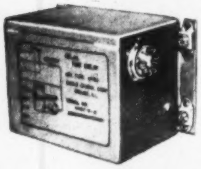

AIRCRAFT
TIMER
Bulletin 815

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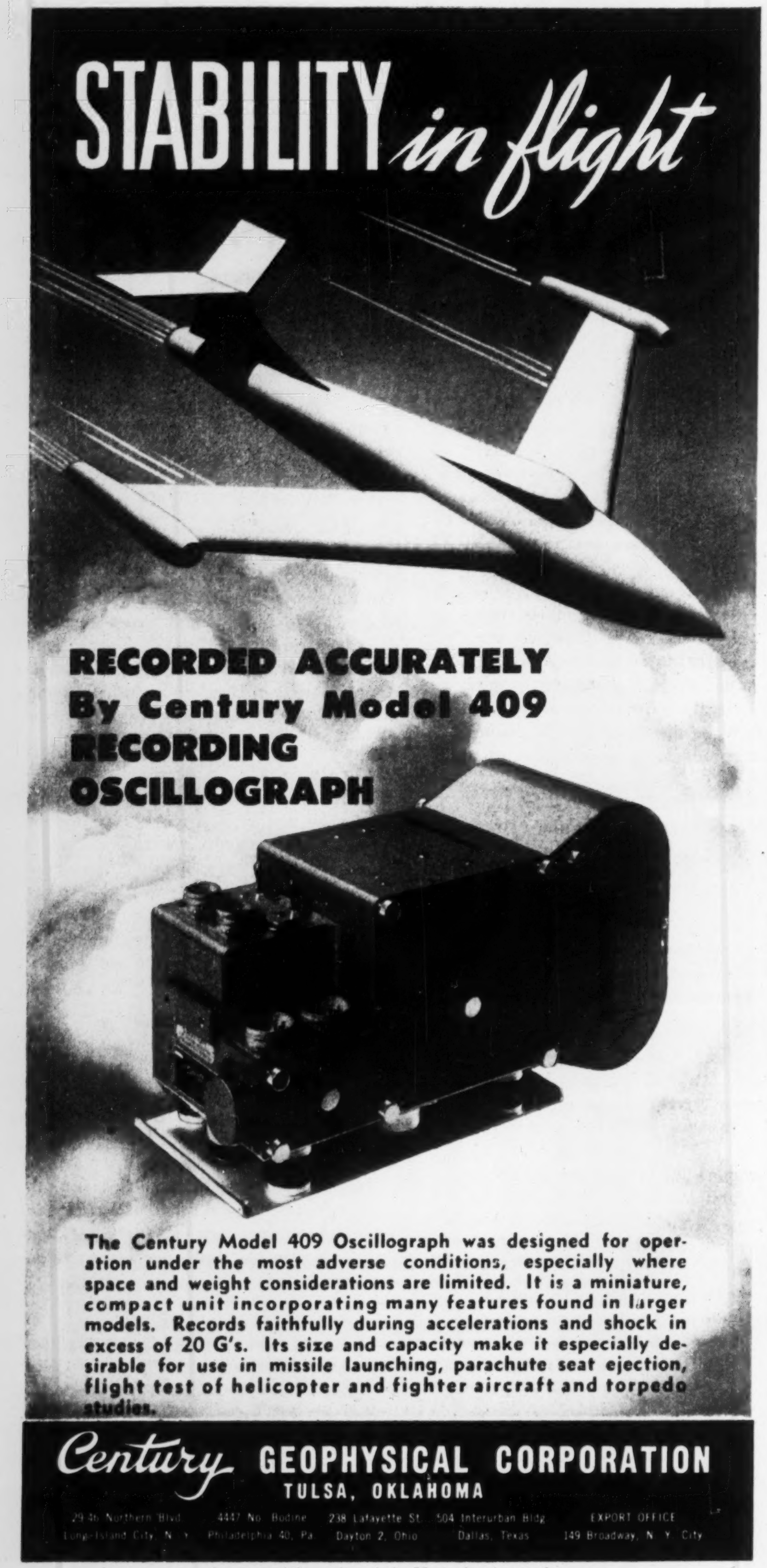
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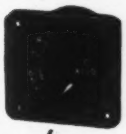

THERMOCOUPLE TYPE

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2¾" Dual shown with removable Bezel. For exhaust temperature range 0 to 1000°C, Chromel-Alumel.

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2" Single, range −50 to 50°C for carburetor-air temperature indication, ring-clamp mounted.

2" Single, range 0 to 190°C for oil temperature indication, ring clamp mounted.

Available in all standard ranges for cylinder head, bearing carburetor-air, coolant, oil, free-air and heating-duct temperatures. For best results, use LEWIS resistance bulbs as sensing elements with LEWIS instruments. Any of above instruments may be supplied with type A-1 bezel if specified.

AIRCRAFT RESISTANCE BULBS AND THERMOCOUPLES

FOR BEST RESULTS USE LEWIS INSTRUMENTS WITH LEWIS BULBS AND THERMOCOUPLES

STANDARD AN5525-1 with 1⅞ in. stem

STANDARD AN5525-2 with 4 in. stem

AN5540-1

AN5540-2

AN5545-1

AN5541-1

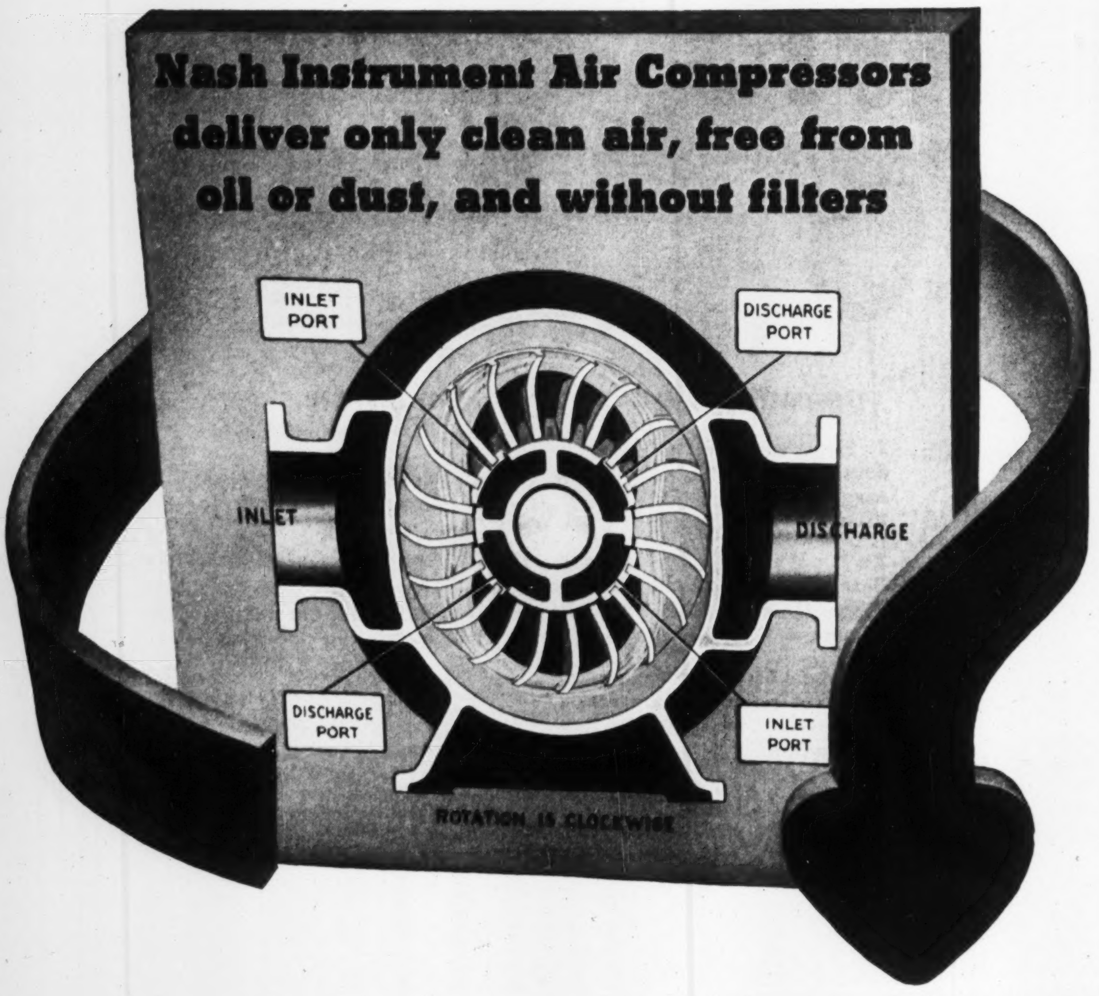
In addition to the standard "AN" Types illustrated, we manufacture thermocouples for test work as well as special types to customer's specifications.

THE LEWIS ENGINEERING CO.

Manufacturers of *Complete* Temperature Measuring Systems for Aircraft

NAUGATUCK, CONNECTICUT

For more information circle **12** on inquiry card.


Nash Instrument Air Compressors deliver only clean air, free from oil or dust, and without filters
INLET PORT
DISCHARGE PORT
INLET
DISCHARGE
DISCHARGE PORT
INLET PORT
ROTATION IS CLOCKWISE

Here is Why!

You can dispense with oil filters and dust filters when you install ®Nash® Clean Air Compressors. You can save the cost of maintaining these devices. You can greatly reduce instrument maintenance costs. For the Nash employs no internal lubrication, therefore no troublesome oil is in the delivered air. Moreover, air from a Nash is thoroughly washed and cooled as it passes thru the pump. Dust in the plant atmosphere, even fly ash, is immediately removed.

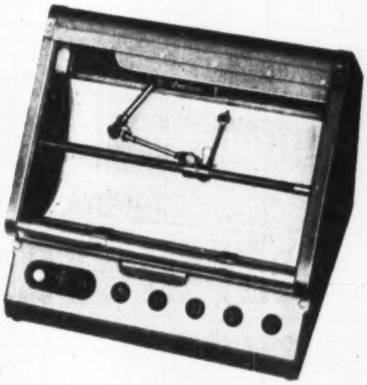
®Nash® Clean Air Compressors are simple, with only one moving element. No valves, gears, pistons, sliding vanes, or other enemies of long life and constant performance complicate a Nash. No aftercoolers are needed. You will find it profitable to investigate these pumps, now.

No oil filters.
No dust filters.
No internal lubrication to contaminate air handled.
No internal wearing parts.
No valves, pistons, or vanes.
Non-pulsating pressure.
Original performance constant over a long pump life.
Low maintenance cost.

NASH ENGINEERING COMPANY
370 WILSON, SO. NORWALK, CONN.

COMPUTERS–CONTROLS–COMPONENTS

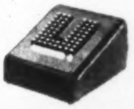
BY LIBRASCOPE



X-Y PLOTTER & RECORDER

A compact desk or rack-mounted instrument for recording two independent variables on standard graph paper, from either analog or digital inputs as continuous curve tracings or point plots. Handles direct or remote mechanical shaft rotations without modification. Special inputs to meet customer applications. For digital operation the following converters are standard:

PUNCHED CARD CONVERTER
Converts punched card data to discrete point plots.



DECIMAL KEYBOARD
For manual point plotting.

BINARY CONVERTER
Consists of 2 channels of 9 binary digit capacity.

SINE WAVE GENERATOR

Used in frequency syntheses to determine data on transfer functions of automatic control systems and components, esp pneumatic.

COMPUTERS TO ORDER:

Librascope manufactures mechanical and electrical analog computers and digital computers for military and commercial purposes. You are invited to submit your special computer requirements to our engineering staff.

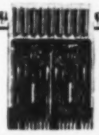
ELECTRONIC COMPONENTS:

ANALOG-DIGITAL CONVERTER

A shaft position to digital encoder, 2" in dia., handles up to 19 digits per unit, utilizes unique, non-ambiguous brush system.

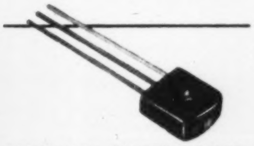
MAGNETIC AMPLIFIERS:

Librascope manufactures ultra-fast magnetic amplifiers for industrial servo-controls, analog and digital computers, and servo-stabilization networks.



PACKAGED CIRCUITRY:

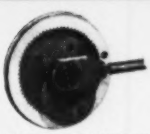
Flip-flop cards, scan matrices and other miniaturized electronic packages are available to customer specifications.



READ AND RECORD HEADS

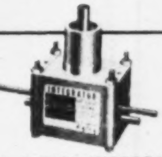
For recording or reading of magnetic drum memory systems in digital computers. High read-back signal, low noise factor.

MECHANICAL COMPONENTS



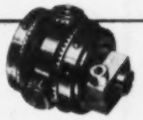
SINE-COSINE MECHANISM

Self-contained unit converts angular rotation into linear sine and cosine movements or solves many trigonometric functions.



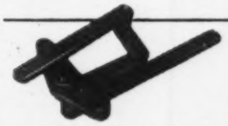
BALL & DISC INTEGRATOR

Precision unit with lifetime lubrication. Used in totalizing, rate determination, differential analysis. Also serves as closed loop servo-element or variable speed drive.



HOLLOW SHAFT DIFFERENTIAL

Precision computer component for measuring angular positions or velocity sums. May be installed or removed without disassembly of unit or differential itself.



LINKAGES

Various linkage computing elements are available, including: addition-subtraction linkages, linkage multipliers and function generators to express exponential, logarithmic and square root functions.

ENGINEERS, PHYSICISTS AND MATHEMATICIANS:

for a rewarding career with a company that offers optimum stability with job diversification, write LIBRASCOPE today. Address inquiries to Dick Hastings, Director of Personnel

Computers and Controls

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potentiometer type transducers
for use at temperatures between − 60°C. and +160°C.

Designs available permit single or multiple range linear output from non-linear input function, and operation over wide ranges of environmental conditions.

for
- **PRESSURE**
- **ALTITUDE**
- **AIRSPEED**
- **ACCELERATION**
- **PRESSURE SWITCHING**
- **ALTITUDE CONTROL**

Designs available for operation to 285°C.

Request Catalog #653.

RAHM INSTRUMENTS, INC.
12 WEST BROADWAY, NEW YORK 7, N. Y.

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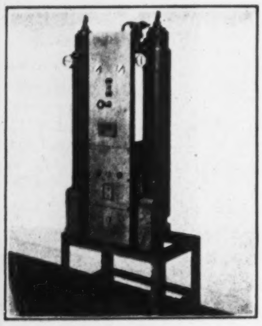
STILL INDUSTRY'S FIRST CHOICE!



ANDERS DEHYDRATORS keep air and gases CLEAN and DRY and free from oil and water vapors

ANDERS DEHYDRATORS are available in 22 standard sizes for 1 to 10,000 instruments—for high and low pressure use. (Larger or special designs for air or other gases and Liquid Hydrocarbons.)

For full information and engineering data address

Anders Compressed Air Dehydrators THE ANDERS-LYKENS CORPORATION
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"A DRY AIR-LINE NEVER RUSTS"

Mfgd. in Canada by
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Weston
Toronto 15, Canada

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We specialize in ultra precision gears and gear assemblies for differentials, subminiature motor gear heads, gyros, servos, etc.

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FINE PITCH PRECISION
INSTRUMENT GEARS?

Let us submit our quotation covering your requirements.

- **FABRICATION**
- **HOBBING**
- **HEAT TREATING**
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100% inspection rendered on all gears made to A.G.M.A. Standard covering tooth form, total composite error, quality, etc. Individual inspection graph charts furnished if required.

BELLMORE GEAR CORP.
2307 Bellmore Ave., Bellmore, N. Y.
Telephone SUnset 5-5000

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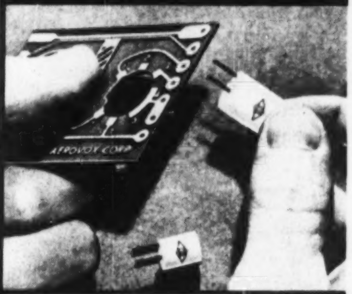
PW SERIES

CINEMA *resistors*

for

PRINTED WIRING AND AUTOMATION

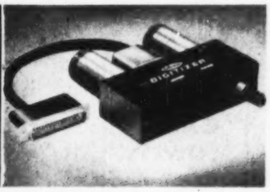
A "first" in printed wiring component design. Precision wire-wound resistors in accuracies from 1% to .05% in resistances from .1 Ohm to 9 Megohms. Write for Bulletin C1034 covering the new PW Encapsulated Resistor.



CINEMA ENGINEERING CO.
DIVISION AEROVOX CORPORATION
1100 CHESTNUT ST. • BURBANK, CALIF.

For more information circle **18** on inquiry card.

Automation Data Reduction Digital Systems



These electromechanical products designed and manufactured by Coleman can save you money by speeding up data reduction and increasing accuracy.

DIGITIZER® (see illustration)—A shaft position decimal converter which actuates card or tape punching machines, printers, and other data storing or indicating devices. Digitizers are used in AUTOMATION systems to digitally start and stop mechanical motion.

OSCILLOGRAM READER—By recording trace deflection measurements directly into punched card machines, reading time can be speeded up by a factor of 7 to 10. Practically no operator experience is necessary to achieve fast and highly accurate results.

BROWN RECORDER KIT—Most models of Brown Recorders can be converted for digital readout in a matter of minutes.

POWERED COMPARATOR—A machine which measures image position on 5½ inch film to an accuracy of ±.00039 inches and automatically records this digitally in data storing and tabulating machines.

BOREADER—A machine for reading 35mm phototheodolite camera film to an accuracy of ±.00039 inches and automatically recording up to 44 digits onto punched cards with the push of a button.

BINARY DIGITIZER—A shaft position binary converter which produces unambiguous straight binary output in capacities up to 15 bits.

Write for brochures describing these and other products. Representatives in many cities.

Coleman ENGINEERING COMPANY, INC.
6040 West Jefferson Blvd. Los Angeles 16, Calif

For more information circle **19** on inquiry card.

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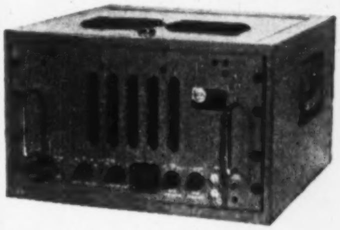
for reliability

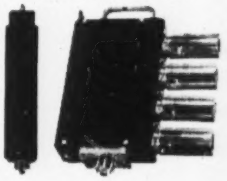
★ ELECTRONIC COUNTER MODEL 111



- General purpose events counter.
- Pulse input—0-100 kc;
- Sine Wave Input—10 cps—100 kc
- Ambient Temp. Range −20° to +150° F.
- Input metering and self checking.
- Count Accuracy of ±1 unit in 100,000.
- Plug-in, sub-assembly construction.
- 99,999 Counter Capacity

. . . accuracy

★ PLUG-IN DECIMAL COUNTER ZA-10057



- Rise Time of 0.05 microsec. min. and 2.0 microsec. max.
- Pulse Duration of 1 microsec. min. and 10 microsec. max.
- Input of 32 volts min. and 50 volts max.
- Etched circuit construction.
- Range of 0-100,000 pulses per sec.

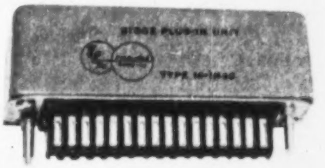
. . . versatility

★ EECO PLUG-IN UNITS

- 30 Standard units including amplifiers and flip-flops.
- Units also built to customer drawings.
- Can be repaired readily when necessary.
- Take-apart construction feature.
- Die-cast container with baked enamel finish.

. . . compactness

DIODE PLUG-IN UNITS



- Types include 8, 12 and 16 diode capacity.
- Take-apart construction feature.
- Die-cast container with baked enamel finish.
- Improved Blue Ribbon polarized Amphenol header

★ Ruggedized and moisture-fungus proofed
★ Premium components used
★ All items individually tested

Write Dept. HB for additional information

EECO PRODUCTION COMPANY
827 South Vermont Ave., Los Angeles 5, Calif.
DUnkirk 5-3026

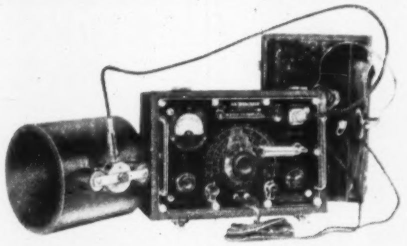
For more information circle **20** on inquiry card.

ULTRASONICS for non-destructive MEASUREMENTS

from one side of the work with accuracies as great as 0.1%

VIDIGAGE®
Direct-Reading Thickness Tester

AUDIGAGE®
Portable Thickness Tester



with an infinite number of ranges between 0.015" and 6.0" of steel or equivalent, with accuracies from 0.1% to 2.0% according to applications. Plug-in oscillators and transducers on cables 25 to 1000 feet long; ideal for quick, accurate production checks on sheets, tubes and odd-shaped sections.

for thickness from 0.040" to 6" and 1/16" to 12" of steel or equivalent, with accuracies to 1.0% according to application. Transducers of many sizes and shapes, extension cables; powered by dry cells or AC. For corrosion inspection in the field and production tests.

COMPLETE LITERATURE ON REQUEST

BRANSON INSTRUMENTS, inc.
electronics development production
443 FAIRFIELD AVE · STAMFORD · CONN.

For more information circle **21** on inquiry card.

Turn the unknown into useful data

with Consolidated Data-Processing Instrument Systems

The most complete family of compatible data-processing instruments available today—useful in every stage of scientific, engineering and industrial work from the most basic investigations to tests of full-scale production models under real operating conditions—Consolidated's line of data-processing instruments includes:

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Consolidated Engineering
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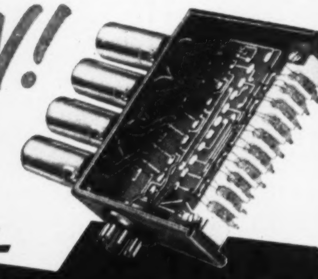
NEW!

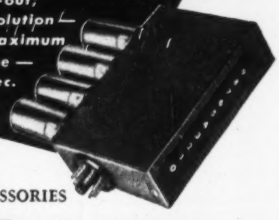
PRINTED CIRCUIT LOWERS COST on...
Detectron



DECIMAL DECADE TOTALIZER

Incorporating printed circuitry into the TU-100P makes it possible to reduce the selling price by producing more uniform units, faster and more efficiently. Greater operating stability through better heat dissipation made possible by improved physical layout. Standard octal plugs assure adaptability to most existing high speed counting equipment.

Direct illuminated read-out; pulse pair resolution— 5 microseconds; maximum counting rate— 100,000 per sec.



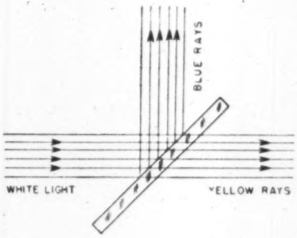
A Complete Line of:
FREQUENCY COUNTERS
RADIATION SCALERS
DECADE TOTALIZERS • ACCESSORIES

COMPUTER-MEASUREMENTS Division of THE Detectron CORP.
5528 Vineland, Dept. 85-A, North Hollywood, Calif.

For more information circle **23** on inquiry card.

FS MULTI-LAYER INTERFERENCE FILMS

Dichroic & Achromatic Beam Splitters



Chromatic Spectral Selection Effect; a certain portion of the spectrum is reflected, the remainder transmitted.

Achromatic Spectral Selection Effect; the incident light is split into two beams, one reflected, one transmitted, each beam retaining the spectral properties of the original incident beam.

Transmission or reflection peaks as high as 85 to 90% but the spectral bands are relatively broad.

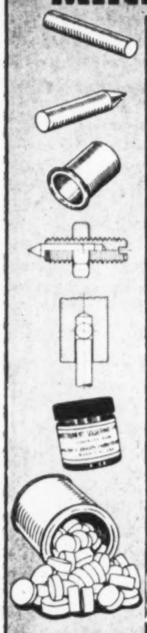
Submit your problems and ask for bulletin MI-318 giving graphs of standard types now available.

FISH-SCHURMAN CORPORATION
68 Portman Road, New Rochelle, N. Y.

Fish-Schurman

For more information circle **24** on inquiry card.

MINIATURE PARTS



CUSTOM MANUFACTURE OF SMALL PARTS

- Shafts, Staffs and Pivots of Special Pivot Steel, Heat-Treated and Metallographic-Polished. • Tubular Products up to 3/8" Diameter, Cut, Flared, Swaged, Formed and Burr-Free Alloy or Silver Plated. • Screw-Machine Products up to 3/16" Diameter. • Roll-Threading and Knurling to Close Tolerances. • Centerless and Surface Grinding with Special Facilities for Ceramic Rods and Shapes. • Light Punch-Press Work.

SERVICES FOR CUSTOMERS' PARTS

- A Multitude of Services are Available for Customers' Parts at Any Stage of Manufacture. These Include: Controlled-Atmosphere Heat-Treating, Centerless Grinding, Surface Grinding, Knurling, Thread-Rolling, Swaging, Drilling, Milling, Burr Removing, Metallographic, Polishing, Barrel-Plating in Alloy or Silver.

ASSEMBLY SUPPLIES

- "Welton" Non-Corrosive Instrument Solder Paste. • "Weltonoil" Treated Buttonwood Pith.

APPARATUS DESIGN SERVICES

In Connection with the Design and Fabrication of Precision Miniature Parts.

ENGINEERING ASSISTANCE ON ALL ITEMS

Welton V. Johnson
ENGINEERING COMPANY INC.
87 SUMMIT AVENUE • SUMMIT, N. J.

For more information circle **25** on inquiry card.

Non-Destructive and Physical TESTING and MEASURING Instruments *for quality control*

CARSON-DICE ELECTRONIC MICROMETERS	Direct measurement of thickness to .000020—not a comparator. Presureless measurement—eliminates "feel" as a source of error. Applicable to hard or soft materials, conducting or nonconducting. Unaffected by temperature, vibration, leveling or aging of tubes.
CYCLOGRAPH	Automatic or manual high-speed sorting of metal parts by 10 metallurgic characteristics. Insures uniform quality, sorts up to 300 pieces per minute. Salvages mixed lots non-destructively, and is applicable to raw stock, semi-finished or finished parts—any size.
ULTRASONIC METROSCOPE	Measures wall thickness from one side only. Detects internal defects non-destructively in sheet, plate, and flat stock. Locates imperfect bond between clad metals.
MICROHM METER	Measures electrical resistances as low as 1 Microhm (.000001 ohms). Portable, 5 range instrument for field or shop use. 2% accuracy. Self-contained power supply. Measures contact resistance in large circuit breakers without disassembly. Quality control of small electrical assemblies and for inspection of incoming raw materials. Basic instrument for checking "cleanliness" of aluminum prior to spot welding.
ADRIAN "QC" FLUOROSCOPE	For visual discovery of internal defects in light weight materials. Class "A" Cabinet—complete operator protection. Quality control at low cost.
DICE MEGOTRON:	For Dielectric absorption testing. Used for insulation testing of power plant, substation and underground equipment.

and many other testing and measuring instruments
Whatever your test problems
WRITE DICE

ULTRASONIC
HYDRAULIC
HARDNESS
RESISTANCE
MAGNETIC
HYDROSTATIC
DUCTILITY
INSULATION
METAL DETECTORS
X-RAY
SPRING
MICROMETER

J. W. DICE CO.
1 ENGLE STREET ENGLEWOOD 9, N. J.

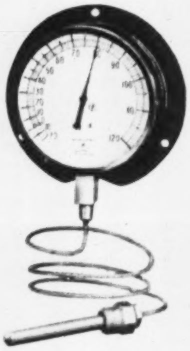
For more information circle **26** on inquiry card.

MARSH Dial Thermometers

0
50
100
150
200
250
300
350
400
450
500

Rigid Stem Type

A dial thermometer that gives highly accurate temperature indication at the point of measurement. It is the bourdon tube vapor tension type which responds quickly to temperature changes. Made in ranges for practically all services.



Remote Reading Type—

A dial thermometer that provides temperature readings from distant or otherwise inaccessible points of measurement. Operates on vapor tension and can therefore be supplied with extremely long connecting tubing. Temperature ranges for practically all services.

MARSH INSTRUMENT CO.

Sales affiliate of Jas. P. Marsh Corporation
Dept. 8, Skokie, Ill.
Export Dept., 155 E. 44th St., New York, N. Y.

For more information circle **27** on inquiry card.

NEW HUMIDITY SENSING TRANSDUCERS—ELECTRICAL AND MECHANO-ELECTRICAL

INSTANT RESPONSE, fastest sensing elements for industry, research.
MICRO-ACCURACY, within 0.2% at given point or portion of scale.
UP TO 240° F for continuous operation, higher intermittent limit.
LONG LIFE, most rugged, dependable, synthetic humidity sensors.
NOT SOLUBLE in water, resistant to most chemical fumes.

MEASURE CONTROL OR RECORD ANY RELATIVE HUMIDITY

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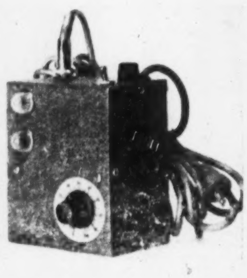

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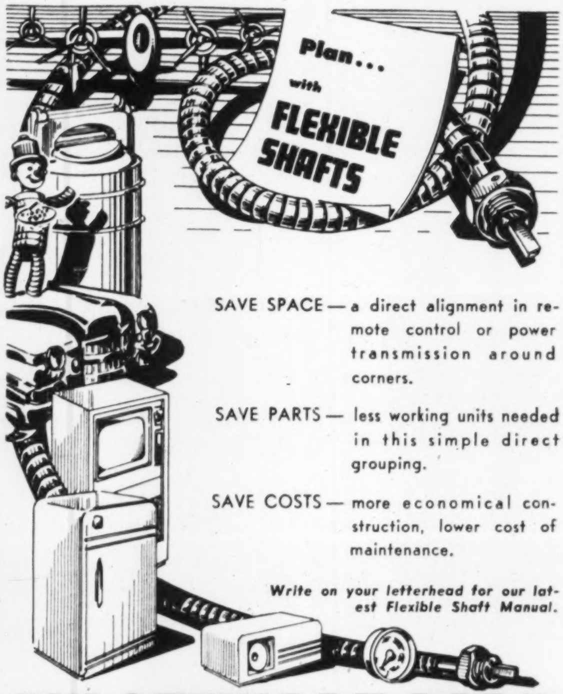

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CHAPTER I
THERMOMETRY

By M. F. BEHAR

PART 1—FOUNDATIONS OF TEMPERATURE MEASUREMENT

1. Introductory Notes

INDUSTRIAL conditions compel a redefinition of the laboratory meaning of "results." Temperature gradients in many pieces of equipment make it hopeless to expect to measure "the temperature." In large drying compartments the gradient may exceed 50 F. when the desired temperature is only about 300 F., especially when trays or other obstructions prevent good circulation. The measurement of the temperature of non-incandescent pieces of solid materials inside an oven or other apparatus is also a difficult task. Even in the case of an empty oven—empty but for air or gas—the readings of a thermometer bulb or thermocouple junction will ordinarily be affected by conduction along, and by radiation from and to, the bulb chamber, well, or socket. When the air or gas is in motion, as in a jet or rocket, or in a low-velocity flue or duct, there is no such thing as "the" temperature and what is required for exact and complete knowledge is not a measurement but an investigation. But aren't flue gas thermometers in constant use everywhere? Certainly; and their successful use provides an illustration of the Instrument Man's "happy medium" view of temperature measurement and control:

1. Too-painstaking scientific methods and the use of delicate non-industrial temperature instruments are unnecessary for the successful routine conduct of processes in industrial plants.

2. Measurements of "the temperature" will be dependable and significant if properly-selected instruments are properly installed, with special care that their bulbs or couples be placed where the temperature is representative. Actual immersion is not always necessary; in the operation of open-hearth furnaces, for example, radiation pyrometers which continuously measure the roof temperature serve to control the temperature of the liquid steel; and the steel temperature itself, as a rule, is only measured from time to time by means of immersion-type radiation blow tubes or sheathed thermocouples.

3. Automatic temperature control can be realized if the primary element be sufficiently responsive to temperature variations, the other elements adequate for their respective functions, and the whole properly installed on equipment that lends itself to control.

After all, these statements are almost self-evident, for they imply that the process equipment (a 10,000-hp. boiler or a candy kettle) must be suitable for the use of temperature instruments: and that the instruments must be reliable.

But before dealing with temperature instruments, it is well to take up that peculiar thing, Temperature, which they measure and control.

Just what is temperature? For more than three centuries after thermometers began to be manufactured, not even the world's greatest scientists answered this question satisfactorily; about two centuries ago they formulated a definition for dictionaries: "Temperature is the degree of sensible heat of a body." This definition was satisfying to the general public—and still is. Less than a hundred years ago, scientists finally abandoned the view that heat was a substance and agreed that heat was a form of energy. In fact, heat is not a special form of energy but a manifestation or an aspect of energy: heat is simply the name of the energy transferrable from one body to another by radiation, conduction or convection —or by a combination of these three thermal processes.

Modern authors of scientific books give a limited definition of temperature which is rigorously correct, for it is the mathematical expression of verifiable laws of nature—the laws of thermodynamics. Here it is:

$$T_2/T_1 = Q_2/Q_1$$

This exact mathematical definition can, of course, be expressed in words. Here is this definition in the words written in 1848 by William Thomson who later became Lord Kelvin:

"The absolute values of two temperatures are to one another in the proportion of the heat taken in to the heat rejected in a reversible thermodynamic engine with a source and refrigerator at the higher and lower of the temperatures, respectively."

Here is another wording—perhaps the briefest: "Temperature is the reciprocal of Carnot's function." In terms of heat and entropy this means

$$T = dQ/dS$$

The thermodynamic definition of temperature, though unquestionably exact, is limited in that it defines the temperature of a BODY of solid, liquid or gaseous matter. It does not apply, for example, to the temperatures of the various kinds of subatomic particles that make up the atoms and molecules of a body. Thus, this definition lacks comprehensiveness.

2. Temperature as a Measurable

No longer can the subject of measuring the temperatures of subatomic particles be excluded; but, for the sake of convenience, the word "temperature," throughout the remainder of the present chapter, will always mean the temperature of a BODY. (Even a tiny body such as a dust-mote is composed of enough molecules for the statistical assumptions underlying modern views.)

So the question "what is temperature?" can be tabled in favor of a much more pertinent question:

"What kind of a Measurable is temperature?"

Looking up the Classifications of Measurables in the first edition of this book, one finds that there are four answers: First, temperature is a CONTINUOUS-SERIES magnitude as distinguished from a countable quantity. Second, temperature is an INTENSIVE magnitude as distinguished from an extensive magnitude. Third, temperature is a NON-ADDITIVE magnitude. Fourth, temperature is a FUNDAMENTAL magnitude as are length, mass, time, and the electric and magnetic properties of free space.

Combining these four answers:

As a measurable condition, temperature is a continuous-series, intensive, non-additive fundamental magnitude.

Now it becomes possible to formulate a definition of temperature which, though "limited" (in its thermodynamic application to a body) and hence not "precise," is believed to be "correct":

The temperature of a body is the intensity of its heat.

Since every body in the universe has thermometric properties, the difficulty of defining temperature in terms other than human senses did not prevent the invention of many types of thermometers and pyrometers after the end of the sixteenth century. What makers and users wanted to measure was

QUICK-REFERENCE DATA ON TEMPERATURE SCALES, ETC.

Temperature	Celsius* (centigrade)	Kelvin (abs. C.)	Fahrenheit	Rankin (abs. F.)	Réaumur
Steam point	100.000	373.16	212.000	671.69	80.0
Ice point	0.000	273.16	32.000	491.69	0.0
Abs. zero	−273.16	0.00	−459.69	0.00	

*Standard name of scale by international agreement, 1948.

$$\text{Deg. F.} = \frac{9\ (\text{deg. C.})}{5} + 32 \qquad \text{Deg. C.} = \frac{5\ (\text{deg. F.} - 32)}{9}$$

but when converting temperature *differences* or *ranges* or *spans:*

9 F.deg. = 5 C.deg. 5 C.deg. = 9 F.deg.

and bear in mind the order of the numerics and letters, for the difference between 200 deg. F. and 150 deg. F. (for example) is not "50 degrees Fahrenheit" but "50 Fahrenheit degrees" (written 50 F.°).

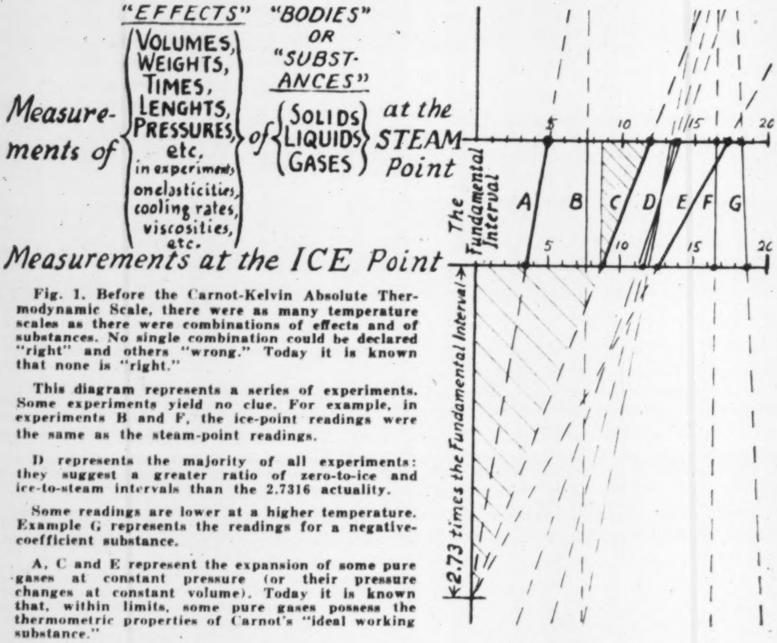
"EFFECTS"
"BODIES" OR "SUBST-ANCES"
Measure-ments of
VOLUMES, WEIGHTS, TIMES, LENGHTS, PRESSURES, etc. in experiments on elasticities, cooling rates, viscosities, etc.
of
SOLIDS
LIQUIDS
GASES
at the STEAM Point
Measurements at the ICE Point
The Fundamental Interval
2.73 times the Fundamental Interval
A
B
C
D
E
F
G
5
10
15
20

Fig. 1. Before the Carnot-Kelvin Absolute Thermodynamic Scale, there were as many temperature scales as there were combinations of effects and of substances. No single combination could be declared "right" and others "wrong." Today it is known that none is "right."

This diagram represents a series of experiments. Some experiments yield no clue. For example, in experiments B and F, the ice-point readings were the same as the steam-point readings.

D represents the majority of all experiments: they suggest a greater ratio of zero-to-ice and ice-to-steam intervals than the 2.7316 actuality.

Some readings are lower at a higher temperature. Example G represents the readings for a negative-coefficient substance.

A, C and E represent the expansion of some pure gases at constant pressure (or their pressure changes at constant volume). Today it is known that, within limits, some pure gases possess the thermometric properties of Carnot's "ideal working substance."

simply "the degree of sensible heat" of products being manufactured, of foods being cooked, of people suffering from fevers, of the air indoors and outdoors, etc. Before the eighteenth century, however, such instruments were thermoscopes and pyroscopes rather than thermometers and pyrometers—because their scales did not agree. And it was less than a hundred years ago that scientific knowledge finally made possible a meaning of "degrees" independent of the particular materials—mercury, alcohol, glass, electric wiring, etc.—that were used in making thermometers and pyrometers.

The ultimate International Standard which makes possible the measurement of temperatures is not a tangible thing such as the International Meter or the International Ohm, but a collection of ideas and of detailed instructions for standardization-laboratory workers: a government pamphlet entitled "The International Temperature Scale," summarized on the next page.

The temperature scale is a scale of intensities. Other intensive magnitudes than temperature—voltage and illumination being common examples—are relatively easy to measure because they are additive.

Voltages may be added, subtracted, multiplied and divided. One volt "here" is the same as one volt "there," just as the fact that one yard "here" is the same as one yard "there" permits us to measure a furlong or mile (or a foot or inch by subdivision).

Not so with the temperature scale, for the physical universe is such that a temperature interval "here" is different from the same temperature interval "higher" or "lower." This is true even if we use any non-linear temperature scale: *all the phenomena of nature are different in one region of intensity of heat from what they are in a higher or lower region of intensity of heat.*

The year 1665 probably marks the transition from thermoscopy to thermometry: Huygens urged the use of what today we would call reproducible fixed points. He mentioned ice and boiling water. This *Fundamental Interval,* (see Fig. 1) made possible higher precision, but each improvement in precision raised new questions as to the correctness of different scales.

In 1701 Newton disclosed his cooling-law method of measuring furnace temperature. In 1702 Guillaume Amontons made the important deduction that the absolute zero must be the point where the spring of the air in an air thermometer vanishes. Later in the eighteenth century Daniel Fahrenheit and Anders Celsius proposed systems of graduations, brought refinements (such as barometric corrections) to calibrations at the ice-point and steam-point, and—more important as an advance toward trustworthy measurements—investigated the reliability of various thermometric substances. In this work they were joined by others. Before the end of the century, rigid specifications for manufacture and purity of spirits, mercury, etc., were agreed upon. The art of thermometry would have become the science of true temperature measurements IF all substances, and IF all utilizable effects such as expansion, produced linear scale laws (see Fig. 1). But the scales of "perfectly accurate" thermometers employing different substances did not agree in the region half-way between two fixed points. And the discrepancies were even greater between thermometers employing different utilizable effects of temperature (see Fig. 2).

Well into the nineteenth century, scientists could not know which substance was the preferable thermometric substance. Nor could they deduce whether the combination of an ideal substance and of an ideal utilizable effect would produce a linear or logarithmic or other kind of scale law.

Carnot's great mathematical work on the nature of an ideal heat engine represented a contribution to scientific measurement of temperature by defining the ideal substance.

As already mentioned, in 1848 Thomson (Kelvin) defined the temperature scale in terms of Carnot's ideal substance. But his scale was TOO independent of the properties of actual materials: it could only be seen with the eyes of reason. Not until 1854 did he begin with Joule the famous porous-plug experiments with gases. Not until 1862 did he announce the practical application of his thermodynamic scale to the making of visible thermometers with tangible scales.

The thermodynamic scale, being an absolute scale of heat intensity, made it possible to locate the absolute zero with respect to the fundamental interval; and also to assign fairly exact values to numerous natural fixed points above and below the ice-point and steam-point. Little by little, sources of errors in a number of methods were discovered and minimized. The platinum-resistance method was refined until it became the practical standard which, in turn, permitted the improvement of radiation and optical pyrometers utilizing the fourth-power law and displacement law (see Chapter II) in high temperature work.

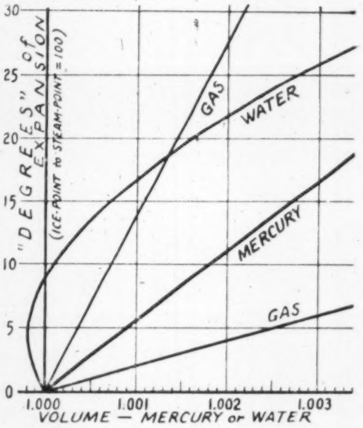

Fig. 2. If the ice-to-steam interval of one type of thermometer (using one substance and one effect) is divided into 100 equal degrees, the scales of all thermometers (using other substances and effects) will not be uniform. In this graph, the "degrees" are obtained by assuming that the expansion of mercury between the ice point and the steam point is perfectly linear. (Only 0.19 of the expansion scale and 0.30 of the "degree" scale are shown in graph.)

The volume of water (Smithsonian tables) is plotted on the same coordinates. Note that as its temperature is raised it contracts at first, reaches minimal volume at 4/100 of the ice-to-steam interval, then expands at an increasing rate.

In the ice-to-steam interval, the readings of gas thermometers correspond closely to those of mercury thermometers and plot as nearly-straight lines. Pure gases were long used as the standards, against which mercury thermometers were calibrated.

Note: Gas pressure or volume graduations not shown, differ on this graph from those for mercury and water.

Decades of such work in national standards laboratories culminated in 1927 in the unanimous adoption, by 31 countries, of "The International Temperature Scale" which described in detail the apparatus, the materials, the procedures and the corrections for the following fixed points:

Point	*Deg. C.*
Oxygen	−182.97
Ice	0.000
Steam	100.00
Sulphur	444.60
Silver	960.5*
Gold	1063

*Revised in 1948. See below.

The 1927 international standard prescribed also the means of interpolating between points and of extrapolating above the gold point. Exactly-specified platinum resistance thermometers are the means prescribed for interpolations between the oxygen point and 660 C.; from 660 C. to the gold point, an exactly-specified thermoelectric method; and above the gold point an exactly-specified monochromatic-optical method.

In 1948 an international conference at Paris issued a slightly-revised scale and the National Bureau of Standards has been using it since 1949. The silver point value is given as 960.8 C. and the value of 1.438 was adopted for the constant c_2 in the radiation formulas for measuring temperature above the gold point. The other changes are of equal interest to readers doing calibration work.

The internationally-approved sets of instruments and apparatus for the fixed points are expensive and require trained operators. (Even the steam-point apparatus involves chemistry, barometry, etc.) For lack of space the elaborate procedures cannot be described in this book, but we may mention the commercial availability of:

(1) secondary fixed-point standards for the highest precision attainable in industrial work, and

(2) adjustable-temperature baths and furnaces designed and built especially for calibrating high-grade thermometers and pyrometers, plus auxiliary equipment likewise designed for such calibration work. Note: An ordinary constant-temperature bath or furnace will not do.

Probable Revision

At this writing (summer 1954) international committees are considering redefining the thermodynamic scale by assigning a number to a SINGLE FIXED POINT (as Kelvin had proposed) instead of assigning the numbers 0.000 and 100.000 to the ice-point and steam-point. This method had previously (1702) been used in practice by Amontons in calibrating his gas thermometers, but he had chosen the boiling point of water, which is difficult to "fix" exactly. Today's scientists favor the triple-point of H_2O, whose temperature on the International Celsius Scale is 0.010 degree: it would be assigned the number 273.170 on the new Kelvin Thermodynamic Scale. The NBS-design triple-point apparatus is inexpensive and fairly easy to use.

3. Accuracy, Sensitivity and Speed of Response

(a) Accuracy

Between the ice point and the steam point, the world's ultimate standard has three numerals after the decimal point; between the oxygen point and the ice point, two; between the steam point and the sulphur point, two; between the sulphur point and the silver point, one; above the silver point, none.

Therefore, any assertion by anyone outside the NBS and similar national institutions that he measures temperatures to a greater number of significant figures is not only boastful but unverifiable.

It cannot be repeated too often that there is no TANGIBLE ultimate Standard like the Standard Meter and Standard Kilogram for measuring intensity of heat. The International Temperature Scale is not a THING shown to tourists who visit the NBS. It is a document. It assigns only three decimals to the values within the commonest temperature ranges—and no decimal to values in the metallurgical and cracking-still ranges.

The question is sometimes asked: "By what right do experimenters with liquid helium, etc., report temperatures such as '2.135 degrees absolute'?" The answer is that cryogenic laboratories have agreed on fixed points of their own and that when refinements dictate revisions, the new values are published (as was done on the I.T.S. for the silver point) so that the corresponding corrections can be uniformly applied to all previously-reported low-temperature experiments.

(b) Sensitivity

In 1886 Langley designed, for his mapping of the sun's infrared spectrum, bolometers sensitive to a millionth of a Celsius degree change. Today, the attainable Ultimate Sensitivity (see page 25 of the first edition of this book) of several types of primary elements is a billionth of a degree. Therefore, it is POSSIBLE to control the temperatures of well-insulated baths and ovens within smaller fractions of degrees than the accuracy to which these same temperatures can be measured. This possibility is recommended to instructors and discussion-group leaders as one topic that "keeps 'em awake."

(c) Speed

Temperature differs from most other measurables in that it cannot be measured instantaneously—the nearest approximations being by the use of a photocell and cathode-ray indicator, by photographing an emission spectrum, etc. It always takes time for a bulb, thermocouple assembly, etc., to attain the temperature of the surrounding medium. Familiar example: even the new fever thermometers advertised as "quick-reading" take at least one full minute to "come to temperature."

Speed of response is not critically important when using indicating thermometers and pyrometers for measuring steady temperatures. It is desirable for recording variations. It is essential for recording fluctuations. It is ABSOLUTELY NECESSARY FOR CONTROL—whether manual or automatic: the slogan "You can't control what the temperature WAS" is as true as when it was first published; so is our old dictum that "dead zones mean dead times and dead times mean dead zones" which means that a controller's primary element must be fast.

The chief cause of slow response is poor heat transfer to the outer surface of the primary-element assembly. The problem of poor heat transfer—in itself—will never be fully solved for all applications. Heat flows from a fluid to this solid (or vice versa) by reason of a difference of temperature. The smaller the difference, the smaller the flow. The flow depends also on the resistances which impede it—exactly as does an electric current. These resistances exist at every surface. They are least when the fluid moves rapidly past the primary element assembly; they are high when circulation is zero. In other words, at zero circulation the conductance of heat has its lowest value—as if a high-resistance FILM surrounded the bulb or couple-protecting tube. Hence the expressions "film conductance" or "film coefficient" (in addition to "surface coefficient" which is a general term including radiation). The film coefficients for gases are, of course, much lower than those for liquids, but different liquids have enormously different film coefficients.

The over-all surface coefficient depends partly on the fluid but it depends also on the material of which the solid is made; also on the nature of the surface (rough or smooth); on its surface shape (with or without fins, etc.) and even on its "color" or spectral absorptance and emittance with emphasis on the infrared. A surface of a certain material may look black to the eye but may be a poor absorber of infrared; a surface of another material may be a perfect visual mirror but may poorly reflect infrared.

The ideal material would have extremely high heat conductivity, of course, but—and this is too often overlooked—it would "weigh nothing" (low density) and it would be "easy to heat" (low specific heat).

Thus the ideal material would have an extremely high THERMAL DIFFUSIVITY—which all-important property is: conductivity divided by (density times specific heat). Diffusivity may also be thought of as heat conductivity divided by heat capacity per unit volume. Remember that diffusivity is the most important thermometric property of protective wells, sockets, etc., for upon its value depends the speed with which a temperature wave travels by conduction. Here are the relative diffusivities or "speeds" of ten materials:

Copper	4.3	Stainless steel	0.25
Aluminum	2.9	Monel metal	0.19
Brass	1.4	Quartz	0.18
Iron (wrought)	0.53	Porcelain	0.026
Carbon steel	0.31	Glass	0.013

Next most important cause of slow response is an obvious one: the total weight of the primary-element assembly. Equally obvious is the geometry or form—specifically the ratio of surface to volume. Other things equal, the sphere is the slowest; next comes the stubby cylinder; and the ribbon or sheet has the shortest response time.

Equally important is the structural complexity or simplicity of the assembly. A one-piece element (no protective cover) has the shortest response time. Next comes the plated or enameled solid element, or the liquid in a thin bulb. Slowest are the rugged industrial assemblies with a number of concentric members and poor thermal contacts.

Readers who have completed a modern course in Heat Transfer will remember that the thermal resistance of a sandwich consisting of a paper-thin mica sheet between two half-inch metal plates may be A HUNDRED TIMES the thermal resistance of a one-inch metal plate. The worst thermal "contacts" are absence of contact: dead-air spaces.

For good automatic control, the primary element must not only be fast but must instantly respond when a change in the controlled temperature occurs. It must be a *quick-starter.* Primary-element assemblies with complex structures are slow starters and the result of dead time is a dead zone. One-piece primary elements with large surface-to-volume ratios are the best quick-starters.

Conclusion: Speed is as important as sensitivity.

4. CLASSIFICATIONS AS PRACTICAL TOOLS

The usefulness of classifications is greatest in the field of temperature measurement and control, where instrument users find a greater number of methods, of utilizable effects, and of systems and components, than in any other field. With thousands of varieties of ready-to-use temperature instruments available, even the nontechnical user (who does no more than purchase) faces problems of selection which cannot be solved by sticking a pin at random in a classified directory but are best solved by the classificatory frame of mind. And the technical user who has the choice of millions of different combinations of components faces almost every day a formidable problem of selection.

Every occupational circle can construct at least one partial classification never attempted before; and use this new classification as a practical tool. In the ceramic industry, for example, the fact that pyrometric cones satisfy requirements is more important than the fact that they have no pointers and scales. The specific fact that a cone slumps at its end point, however, suggests two unusual ways of classifying all temperature instruments:

(A)
1. Continuous scale—the usual form
2. Discontinuous scale consisting of a series of units

(B)
1. Measures once and is discarded
2. Measures intermittently (maximum & minimum, etc.)
3. Measures continuously

Eight Simple Classifications of All Temperature Instruments are given below, each representing a distinct point of view:

(C)
1. Contact
2. Distance

(D)
1. Local
2. Telemetering

(E)
1. Indicating
2. Maximum- or minimum-registering
3. Recording
4. Controlling
5. Combination

(F)
1. Portable
2. Board- or wall-mounted
3. Built-in
4. Convertible

(G)
1. Single-point
2. Selector-switch type

(H)
1. "Ready-to-use" or "factory calibrated"
2. Requires calibration

(I)
1. "Scientific"
2. "Industrial"
3. "Domestic"
4. "Universal"

(K)
1. "Laboratory"
2. "Plant"
3. "Field"
4. "Universal"

Lists (I) and (K) are not genuine classifications (made up of mutually-exclusive categories). A vest-pocket thermometer may be "scientific" or "industrial" depending on the wearer of the vest—and "domestic" when it is clipped to a housewife's apron-pocket. Thus, most vest-pocket thermometers are "universal." Therefore, the categories are not mutually-exclusive.

Another scheme for classifying temperature instruments is by quantitatively graded categories, defined by arbitrary intervals like size classifications, weight classifications etc. Such categories, in their ideal forms, have mathematical infinitesimals for their dividing lines. Their logical use is as supplemental references for cross-classifications. Two examples:

(L)
1. Limits of practicable ranges extend from 0°Abs. to 100°Abs.
2. 3, 4, etc. Similarly defined

(M)
1. \$4.99 or less
2. \$5.00 to \$99.99
3. \$100 to \$499.99
4. \$500 to \$999.99
5. \$1000 or more

All of the above are simple and obvious, but combining them in various ways is a good homework exercise—as well as a means of making decisions in the plant. Although not all combinations are possible, the combination of types from two or more different lists should be carried out. Busy purchasing engineers will find such "exercises" a time-saving tool.

Many industrial temperature instruments are made up of standardized components, some of which are embodied in instruments for measuring and controlling other conditions than temperature. Thus, the instrument part of a gas-filled type recording thermometer is essentially a "recording pressure gage." A man who services such recording thermometers has to think of them (at least part of the time) as pressure-measuring devices. This is true of the men who have designed, sold, purchased and installed these recorders.

Nearly all board-mounted instruments thus belong in several classifications. To look at a self-balancing electrical recording instrument, you cannot tell (unless you read the name-plate or the printing on the chart) whether is it connected to a pH cell, to a radiation-receiver tube, to a resistance coil or to a gas-analysis cell. It might be recording the frequency of an alternator in a hydroelectric plant two hundred miles away.

Since methods—rather than things—are of supreme importance in temperature work, a careful reading of the twelve classificatory schemes given on pages 18-19 of the first edition of this book is recommended. These pertain to general methods of measuring any magnitude. The methods of measuring temperature in particular can be classified in some of these twelve ways, but not in all. (The reader may enjoy sharpening his judgment by deducing the reasons why some of these twelve schemes do not apply.)

5. THE RATIONAL CLASSIFICATION

For some unknown reason the scientists themselves, though always interested in temperature measurement and control, failed for four centuries to apply their own methodology to this field. None of their classifications deserved to be regarded as more than a clumsy list of names—some names utterly lacking precise meanings.

Then America took the lead. The American Institute of Physics, aided by chemical, geological, biological and other American scientific bodies, convened its great Temperature Symposium in 1939 and assigned to one worker the subject of Classification. The following extract from his paper reports how his classification (shown here as Table I) was constructed:

Classify by Methods, Not by Things . . . Since an instrument is a physical embodiment of a method, a fundamental classification according to classes of fundamental measurement methods may be said to be "ideal" in the same sense that the Carnot-Kelvin working substance and the Kirchhoff blackbody are "ideal."

Since a method of measuring temperature is a method of utilizing an effect of temperature, a classification according to fundamental categories of *utilized effects* suggests itself.

Such a classification is here attempted for the first time. For its prime division into a conveniently small number of collectively-exhaustive and mutually-exclusive categories, we may start from a consideration of the fact that the whole practice of temperature measurement is founded on fixed points. It always is because of a *discontinuous* effect of heating or cooling a substance when it undergoes a change of state that this substance has temperatures of equilibrium. Such effects are always *reversible*, and the combination makes possible the use of these fixed points. Therefore the basic methods defining the international standard are those which utilize *discontinuous reversible* effects. The great majority of methods used in practice, of course, are based on *continuous reversible* effects. A pyrometric cone is an example of a *discontinuous irreversible* effect. These considerations lead to the following prime division:

I. Methods utilizing discontinuous reversible effects.
II. Methods employing continuous effects.
III. Methods utilizing irreversible effects.
IV. Combination methods.
V. Miscellaneous methods.

These five mutually-exclusive and collectively-exhaustive categories may be called "Divisions." Each division except the "miscellaneous" should comprise a list of mutually-exclusive and collectively-exhaustive "Classes." Each class would be divided into mutually-exclusive "Types," collectively exhaustive as far as possible. Within each type, the "Varieties" or "Sub-types" may be mere lists.

At each successive stage there is a choice of classification schemes; and opinions will differ. The breakdown of Divisions I, III and IV into perfect classes may not arouse wide interest, but Division II surely challenges the ingenuity of all future workers . . . The table is left incomplete, but it includes suggestions for alternative subdivisions at various stages . . . Class 1 of Division II is not classified: instead of the mere list of fifteen properties (out of 50-odd utilizable) there might be:

a. Mechanical
b. Electrostatic
c. Electrodynamic
d. Magnetic
e. Electronic
f. Chemical
g. Electrochemical
h. Optical
i. Magneto-optic
etc.

But many workers will want to make *this* (mechanical, etc.) the first breakdown of Division

TABLE I—RATIONAL CLASSIFICATION OF TEMPERATURE MEASUREMENT METHODS*

I. Methods Utilizing Discontinuous Reversible Effects

1. *Freezing point.*
2. *Boiling point.*

← A line must be drawn (both meanings) between equilibrium temperature effects which include the International Standards, and all others.

3. *Molecular transformation point.*
4. *Solubility.*
5. *Color.*

Etc.

II. Methods Employing Continuous Effects

1. *Properties of bodies.*
   - a. Thermal expansion, expansivity, expansibility.
     - (1) of gases
     - (2) of liquids
     - (3) of solids

     Instruments are classified by utilized coefficient (linear, cubical); also as cathetometric, extensometric, volumetric, etc.
   - b. Conductivity, resistivity (electrical).
     - (1) of metals, of alloys.
     - (2) of other solids.
     - (3) of electrolytes.
     - (4) of ionized gases, etc.

     Resistance measurement methods classifiable by type of circuit, by type of instrument (deflection, self-balancing, etc.) and in other ways.
   - c. Viscosity, fluidity.
   - d. Refractivity.
   - e. Vapor pressure.
   - f. Magnetic susceptibility.
   - g. Sound velocity.
   - h. Dielectric "constant."
   - i. Elasticity.
   - j. Rotatory polarization.
   - k. Color of transmitted light.
   - l. Color of reflected light.
   - m. Hydrogen-ion concentration.
   - n. Specific heat.
   - o. Compressibility.

   Etc., etc., etc.
2. *Effects between bodies.*
   - a. Simple differences of properties.
     - (1) Expansivities.
       - (a) Bimetallic.

     Etc.
   - b. Effects at interfaces ("junctions," etc.).
     - (1) Solid vs. solid.
     - (2) Solid vs. liquid.
     - (3) Liquid vs. liquid.

     Instruments classified also by utilization of effects, modes of conversion of energy: thermoelectricity, etc.
   - c. Radiation effects.
     - (1) Methods utilizing Stefan-Boltzmann fourth-power law.
     - (2) Methods utilizing displacement of maximum energy density. (Color temperatures, of stars, etc.)
     - (3) Methods utilizing selected band or effective wave-length
       - (a) Measurement of the monochromatic energy by visual matching.
       - (b) Measurement by "extinction" methods, etc. etc.
       - (c) Combinations of (a) and (b).
       - (a) Selection by filtration as in use of red glass.
       - (b) Selection by spectral curve of receiver: photocell, plate emulsion, etc.
     - (4) Methods utilizing ratio of energy at two effective wave-lengths. ("Two-color pyrometry.") (a), (b), etc.: Further subdivision into visual and autometric; then by types of electrical ratio instruments, etc.
     - (5) Spectroscopic, spectrographic or spectrometric methods.

     Etc.

III. Methods Utilizing Irreversible Effects

1. *Fusion.*
2. *Color change.*

Etc.

IV. Combination Methods

1. Methods using a temperature coefficient of an entire assembly. Examples: temperature coefficient of conductance of a thyratron; temperature coefficient of capacitance of a capacitor; temp. coeff. of rate of a clock; t.c. of pitch of almost any musical instr.
2. "Calorimetric pyrometers," "aspiration pyrometers" and other devices requiring transport or transfer or manipulation of the body or of a continuous sample.
3. Methods requiring the introduction of an "indicator" as in line-reversal method.

V. Miscellaneous Methods

(Miscellaneous in the sense of not includable in other divisions.)

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*From "Classifications of Temperature Instruments" by M. F. Behar, 1939 Temperature Symposium of American Institute of Physics. Book title: "Temperature—Its Measurement and Control in Science and Industry," Reinhold Publishing Co., New York, 1941. (This table is a facsimile reproduction of page 350.)

TABLE II
INDUSTRIAL CLASSIFICATION OF TEMPERATURE MEASURING INSTRUMENTS

I. Expansion Thermometers

1. *Liquid-in-glass (Visible-column)*
   - a. Mercury—customary types
     - (1) Industrial (complete protection)
     - (2) Semi-industrial (incl. special-purpose)
     - (3) Miscellaneous (pocket, wall, etc.)
     - (4) Etched-stem ("laboratory," "chemical," "testing")
     - (5) Enclosed-scale
   - b. Mercury — special high-temperature glass
   - c. Alcohol, toluol, pentane, etc.
   - d. Gallium in quartz
2. *Solid expansion*
   - a. Metal and refractory
   - b. Bimetal
     - (1) Integral: one element
     - (2) Two metallic members
3. *Pressure-spring*
   - a. Mercury
   - b. Xylene, etc.
   - c. Vapor-pressure
   - d. Gas

II. Electrical Thermometers and Pyrometers

1. *Electrical Resistance*
   - a. Platinum (standard)
   - b. Nickel, copper, tungsten, etc.
   - c. Semiconductors
2. *Thermoelectric*
   - a. Rare-metals
   - b. Special alloys
   - c. C-SiC

III. Radiation Thermometers and Pyrometers

1. *Total-radiation*
   - a. "Hand"
   - b. Autometric, autographic, etc.
2. *Selective-radiation*
   - a. Visual
     - (1) Brightness
     - (2) Color
   - b. Autometric, autographic, etc.
     - (1) Phototube receiver
     - (2) Photocell receiver

IV. Miscellaneous

1. *Fusion* ("cones," etc.)
2. *Color Change* (of thermoscopic pastes, liquids or pellets).
3. *Solubility*
4. *Sound Velocity*
5. *Electrical "noise"*

etc., etc.

II into Classes, not merely of Class 1 into Types. An argument for this view is that the thermoelectric effect is not mentioned by name. But it is not overlooked: although thermoelectric *power* is property of a body, this property is not utilized *per se* in temperature measurement and hence is purposely omitted from II, 1. What is utilized in thermoelectric instruments is an effect between bodies (II, 2) and specifically an interface effect (II, 2, b.)

[End of quotation]

Traditional Classifications. — These classifications of temperature instruments as things, though unscientific, will always be useful as topical divisions of books and articles. The one made up in 1926 by and for Instrumentation is given here (with additions recognizing new inventions) as Table II.

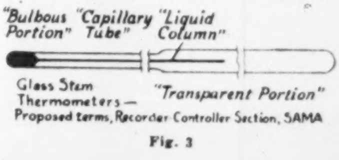
PART 2

MERCURY-IN-GLASS THERMOMETERS

1. General Characteristics

The essential physical parts of a visible-liquid-column thermometer comprise only the tube and the liquid. The tube consists of a large-volume thinwall *bulb* and of a *stem* with a relatively small-volume *bore*. The stem alone is sometimes called the *tubing*—particularly when it is of special glass different from that of the bulb—and in most instruments it consists of a *capillary portion* and of a *transparent portion,* which may be of different glasses.

The smaller portion of the liquid, in the bore, is the *column* or *thread.* To prevent spilling and evaporation, the *tip* of the stem is sealed and therefore the body of gas above the top of the liquid thread in the bore becomes a third physical "part" of the instrument. This gas may be the room air that happens to be left there; or it may be



Glass Stem Thermometers — Proposed terms, Recorder Controller Section, SAMA

Fig. 3

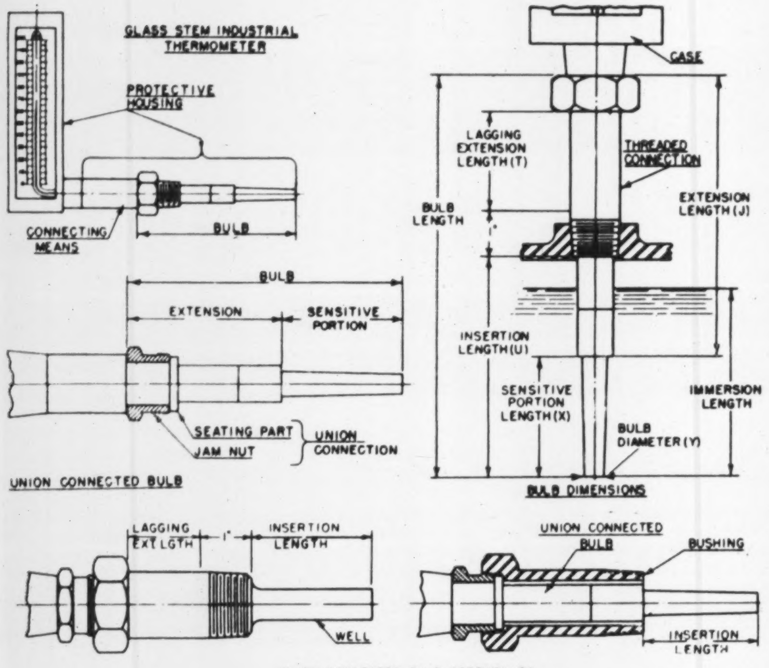

GLASS STEM INDUSTRIAL THERMOMETER
PROTECTIVE HOUSING
CONNECTING MEANS
BULB
CASE
LAGGING EXTENSION LENGTH (T)
THREADED CONNECTION
BULB LENGTH
EXTENSION LENGTH (J)
1"
INSERTION LENGTH (U)
SENSITIVE PORTION LENGTH (X)
IMMERSION LENGTH
BULB DIAMETER (Y)
BULB DIMENSIONS
BULB
EXTENSION
SENSITIVE PORTION
SEATING PART
JAM NUT
UNION CONNECTION
UNION CONNECTED BULB
LAGGING EXT LGTH
1"
INSERTION LENGTH
WELL
UNION CONNECTED BULB
BUSHING
INSERTION LENGTH
UNION CONNECTED BULB ASSEMBLIES

Fig. 4. Showing some of the numerous forms of standard connections of industrial thermometers and giving some of the SAMA's proposed standard terms.

a carefully-measured quantity of pure inert gas deliberately introduced for various purposes. One purpose is to prevent "thread-break" or "column separation." Another is to permit the instrument to be used at temperatures higher than the atmospheric-pressure boiling-point of the liquid.

To prevent injuriously excessive pressures when the thread rises and compresses the gas, there usually is an enlargement of the bore at the tip of the stem, so that the larger portion of the body of gas is in this *expansion chamber* or *upper reservoir*.

So much for the essential physical parts. The device does not become a measuring instrument, however, until it is provided with a *scale*. A plain thermometer, as described above, is usually calibrated by immersion (to a standardized depth) in a series of constant-temperature baths numbering from two to as many as called for in rigid specifications. At each bath, the worker files a tiny mark on the stem opposite the top of the thread. This operation is known as *pointing*. A five-point thermometer is one whose scale is presumably accurate within limits of observation at five such points.

Automatic scale-engraving machines, which follow the calibration curve of each individual instrument, are used for engraving the scales of thermometers after pointing at three or more temperatures. (For a two-point calibration the graduations are merely made uniform.) The residual error is greatest, of course, mid-way between points, but with the uniform-bore tubing available today, a two-point instrument with separate scale may be acceptable for some uses.

It cannot be repeated too often that unless the stem itself is marked—even if only at one point—a separate-scale instrument cannot be trusted. The tube and the scale in separate-scale instruments should be securely attached in proper relation to each other; and the mark on the tube should be so plain that accidental slippage can be detected without using a magnifying glass.

2. MEASURING PROPERTIES OF PARTICULAR INTEREST

Readability.—A number of forms of mercury-in-glass thermometers have had their readability greatly improved by various means. The principal means consists in substituting, for the traditional cylindrical stem, one of approximately triangular cross-section, with a rounded edge facing the observer. This "lens front" magnifies the apparent width of the mercury thread.

This method, though a decided improvement, has been supplemented by arrangement designed to provide *color contrasts* because the lens front *alone* cannot make mercury as visible as brightly-colored alcohols. Strips of white glass and ruby glass, at the back of the stem, appeared on the market more than half a century ago. Since the nineteen-twenties, stem constructions affording greater readability have been brought out. See Fig. 5.*

Attainable Precision.—Theoretically, with an enormous ratio of bulb volume to bore volume, the only limit to precision or Unit Sensitivity (not Accuracy) would be imposed, in a thermometer of convenient dimensions, by the difficulty of seeing the top of a filament-like column and by capillarity effects. Practical limitations of size, weight,

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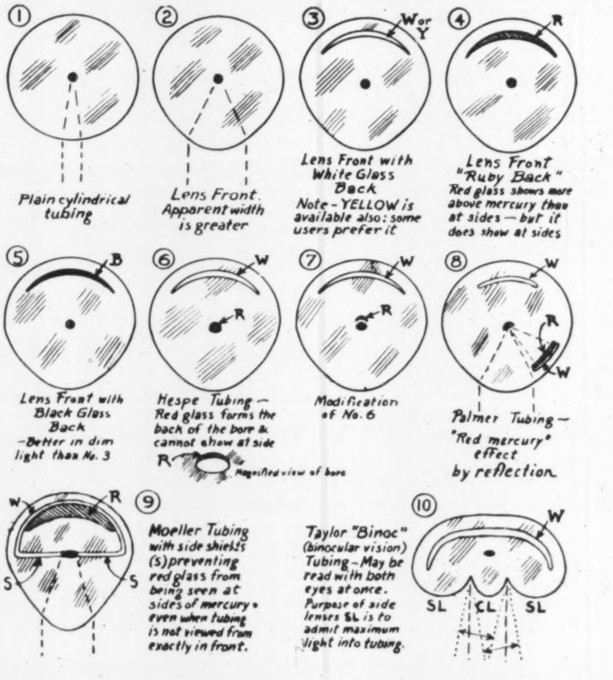
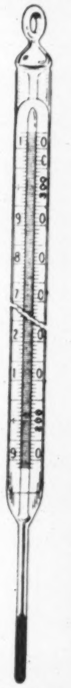
*The author assumes responsibility for imperfect draftsmanship and imperfect presentation of the advantages of each invention.


①
Plain cylindrical tubing
②
Lens Front. Apparent width is greater
③
W or Y
Lens Front with White Glass Back
Note - YELLOW is available also: some users prefer it
④
R
Lens Front "Ruby Back"
Red glass shows more above mercury than at sides — but it does show at sides
⑤
B
Lens Front with Black Glass Back
-Better in dim light than No. 3
⑥
W
R
Hespe Tubing — Red glass forms the back of the bore & cannot show at side
R
Magnified view of bore
⑦
W
R
Modification of No. 6
⑧
W
R
W
Palmer Tubing — "Red mercury" effect by reflection
⑨
W
R
S
S
Moeller Tubing with side shields (S) preventing red glass from being seen at sides of mercury even when tubing is not viewed from exactly in front.
Taylor "Binoc" (binocular vision) Tubing - May be read with both eyes at once. Purpose of side lenses SL is to admit maximum light into tubing.
⑩
W
SL
CL
SL



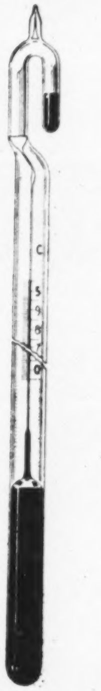


Fig. 5. Some of the methods of improving the readability of glass-stem thermometers.

Fig. 6. (right center) A porcelain-scale laboratory thermometer with relatively large area of bulb surface to bulb volume to improve speed of response to temperature changes.

Fig. 7. (right) A difference-thermometer or Beckmann thermometer. (See text for method of use.)

cost and characteristics of glasses (including fused silica, etc.) create obvious difficulties in the manufacture, calibration and use of theoretically-possible instruments. Moreover, sources of error would make an extraordinary degree of precision (such as 0.01 F. degree) a source of delusion. Finally, electrical thermometers are available for extreme precision work. Therefore, even the finest "test-grade" glass thermometers are seldom made to be read to less than about 0.02 degree (engraved graduations 0.1 degree).

Stability.—No single type of glass can combine all desired properties. Many thermometer makers use different types of glass for bulbs, stems and for the connecting tubing between bulb and graduated stem. This diversification has minimized but not eliminated aging effects. Any piece of glass, even if kept on a shelf, will undergo changes during the years following its manufacture. The glass used in high-grade thermometers has been aged either naturally or by some special process, whereby the *residual* changes occurring in use are minimized.

The elasticity of the glass from which the bulb is blown is a critically important property. Since the bulb is the very portion which is exposed to temperature changes, exposure of a thermometer to temperatures much higher or much lower than its range limits may undo the good effects of the manufacturer's aging process. Always remember that mechanical or thermal shocks may cause invisible changes (in properties if not in dimensions) which will irremediably impair the accuracy of any glass instrument.

Accuracy.—From the viewpoint of the industrial user, readability, precision and stability are the three chief factors contributing to the intrinsic accuracy of glass thermometers. The extrinsic accuracy of a glass thermometer may equal its intrinsic accuracy if it is permanently installed in an application where immersion and other factors (including circulation) all remain constant. *Portable* thermometers are subject to serious errors if not immersed exactly to the mark and otherwise used under calibration conditions.

Slow Response.—Of all widely-used temperature instruments, the liquid-in-glass thermometer has the longest characteristic time. The "quick-reading" laboratory thermometer shown in Fig. 6 is advertised as a "three-second thermometer"—no doubt referring to its response in rapidly-circulating water, in which case its response in stagnant air would be several minutes—which IS quick for a glass thermometer.

3. INDUSTRIAL THERMOMETERS

These widely and importantly used instruments embody the usual glass tube thermometer, but it is completely surrounded and protected by metal and plate glass. The removable plate glass front, framed in aluminum, bronze, or other material, may appear to be a minor item, but it distinguishes those thermometers which really deserve the title of "industrial" from the "oval-back," "open-V" and "miscellaneous" thermometers. Out of more than a hundred thermometer makers in the United States, only a dozen or so manufacture genuine industrial thermometers. In addition to superior mechanical construction, industrial thermometers embody hidden virtues that show up in actual service, and distinguish them further from the "semi-industrial" types. The glass itself meets exacting specifications and the raw tubes are selected with care (we recall seeing a barrel of deliberately smashed rejects in one factory). It is heat-treated. Bulbs and capillaries are made of special-composition glass. A dry, inert gas (usually nitrogen) fills the bore above the mercury and prevents thread-break. Each pair of scales is graduated for its tube, which is pointed at several temperatures; and each tube is so held that it cannot slip. The mercury is of exceptional purity. Colored alcohol and other low-range liquids are supplied for applications where the industrial type of thermometer is desired and where temperatures below −40 have to be indicated.

Several manufacturers have developed various forms of "extra-heavy-duty" and "super-service" mechanical protection. They have also brought out various forms of heat-insulating sleeves to minimize heat conduction between the scale-case and the parts in contact with the wall of the apparatus or pipe. Recent introduction by the plastics industry of heat-insulating materials of metal-like strength has made it possible to have the benefit of this feature without impairment of ruggedness. Among other modern features, mention may be made of the use of a flexible capillary between bulb and tube which permits adjusting at will the angle between bulb and scale-case.

Bare Bulbs.—For many applications, particularly where gas temperatures must be measured, the glass bulb should not be enclosed in a bulb chamber because the lag might be objectionably great. For such applications it is well to specify a bare bulb, protected by a suitable *guard* such as a perforated metal tube of comparatively large diameter.

Principal Sizes of Industrial Thermometers.—Standard scale-length sizes are 7, 9 and 12 inches. The scale cases are between 1½ and 2 inches longer.

High Ranges.—Thermometers of typical "industrial" construction are not recommended for use above 900 F. Special instruments, variously known as tempering-bath thermometers, type-metal thermometers, flue-gas thermometers, etc., when made with care of selected materials, may be exceptions to this statement.

4. BECKMAN OR DIFFERENTIAL THERMOMETERS

If the volume of the expansion chamber or upper reservoir (mentioned at the beginning of this Part) be made as large as that of the bulb, there will be no danger of overranging a short-range thermometer. The *difference thermometer*, also known as the Beckmann type (Fig. 7) not only employs this idea but is so designed that (1) some mercury can overflow from the top of the bore into this reservoir and stay there; and (2) some mercury can be transferred back by manipulating the instrument. Every time this happens, of course, the range is displaced—which is exactly what the inventor desired that the user should be able to do at will. Beckmann thermometers may be graduated in hundredths of a degree (F. or C.). Their obvious purpose is to measure small (say 2-deg.) temperature changes or temperature differences with a relatively small error—small in percent of this change or difference. Among features of improved designs may be mentioned an auxiliary scale for the upper body of mercury and a "dropping" arrangement whereby each drop of mercury has a rated value in relation to the auxiliary scale. This minimizes the drudgery of "setting" the instrument to the desired correspondence between the mid-point of its scale range and a definite temperature.

5. HIGH-TEMPERATURE VISIBLE-COLUMN THERMOMETERS

Mercury-in-glass thermometers should not, *as a rule*, be used above 850 F. The use of special glasses and glass-like materials, with higher softening points, permits higher *mercury* ranges by permitting the gas to be compressed and the boiling-point of the mercury raised, without injurious effects. The other solution of the problem is to use gallium (boiling-point around 2900 F.) in a tube made of one of these special materials, such as fused quartz.

"*Hyperthermometers*" are scaled up to 1200 F. or 650 C. They are similar to the etched-stem instruments in general appearance, the main difference being in the glass which has a higher softening point.

6. LOW-TEMPERATURE VISIBLE-COLUMN THERMOMETERS

Best-remembered numbers in thermometry are 0 and 100; 32, 212 and 180; and also −40 where C. and F. meet and where mercury freezes. (Exact f-p., −38.783 C.) The principal thermometric liquids used for measurements below −40 deg. are:

Liquid	*Customary limits of scale graduations*			
	Lower		Upper	
	C.	F.	C.	F.
Alcohol	−60	−80	300	150
Taluol	−95	−130	30	80
Pentane	−200	−330	30	80
"Pro-pro"	−220	−360	30	80

(Equal volumes of propane and propylene; C. Hochnadel, *RSI*, May 1954, p. 524)

It may be worth mentioning also that if, instead of pure mercury, a eutectic alloy of 91.5% mercury and 8.5% thallium is used as the thermometric liquid, the lower point of the range can be brought down to −60 C. or −76 F.

PART 3

SOLID EXPANSION THERMOMETERS

1. Differential Linear Expansion Thermometers

The first industrial devices for measuring temperature by the change of length of a solid were clay cylinders used by Wedgwood in the 18th century. The expansion of platinum was used by Daniell for high-temperature measurement early in the 19th century. All such devices utilize the *differential* expansion of two solids, for there must be a reference member which does not change its dimensions as does the thermometric member. The earliest pyrometers regularly manufactured for industrial use, therefore, consisted of two rods or tubes. At the furnace end of the device the two materials were attached; at the dial head of the device, the ends of the two rods or tubes were free to move in relation to each other and this motion actuated the pointer. There are modernized forms several feet in length, the stem consisting of an outer metal tube and of an inner refractory rod; and the dial generally being perpendicular to the stem.

The expansion coefficients of all known solid materials—even "pure" precious metals—change as a result of repeated cycles of temperature changes. Such instruments should seldom be used above a dull red heat; and 1000 F. is the usual upper limit when the tube is made of any kind of iron or steel. Neither can the refractory member be expected to remain an invariable standard of reference. However, one frequently hears an old-timer say that such instruments "settle down" after a few months of being "cured" by actual service, and that after resetting the pointer at the end of such a cure the instrument stays accurate for many years. One may assume that the instruments were found accurate because they were designed to be read to the nearest 10 degrees or so.

Rod-type units cannot be dismissed without mentioning their high power as compared with units which deflect. Even allowing for the much smaller travel and for the elasticity of a "rigid" rod, the product of available force times distance is hundreds of times greater for the rods than for the spring-like elements. Since energy is the deciding factor in large (say 12-in. dial) instruments and in the operation of valves, the rod element will not soon pass out of the picture. It is successfully used in many inexpensive (but not poor-grade) thermostats for mass-produced ovens and other appliances—not only for on-off control by operating snap switches, but also for proportional control by operating fuel valves (either directly or through an air valve to a diaphragm-motor valve).

Rod-type units, because of their high power, make excellent primary elements for pneumatic telemetering.* The combination of a rod thermometer and a 3-to-15-psi. transmitter would seem to offer attractive possibilities.**

2. Differential Solid Cubical Expansion Thermometers

In the instruments just dealt with, the actual measurement is that of the difference between two lengths—which of course is itself a length.

The difference between two volumes is itself a volume. Therefore, the indicating or recording means of a differential solid cubical expansion thermometer must be a volume-indicating (or -recording) device.

The bulb of a differential solid cubical expansion thermometer comprises an outer shell and an inner shell nearly filling the outer shell. For the sake of speed of response, the outer shell is a high-coefficient metal and the inner shell is a refractory or low-coefficient alloy. The outer shell, therefore, is the thermometric member. A liquid fills the volume between the outer and inner shells. In the simplest form (not shown) the indicating means would be a vertical small-bore transparent tube open at the top. In the commercial form the liquid actuates, through connecting tubing, a bellows or helix or Bourdon tube. The liquid flows FROM the helix INTO the bulb as the measured temperature RISES, and vice versa. The ideal liquid would be incompressible, would be perfectly non-thermometric (zero thermal expansivity) and would neither freeze nor boil at the low and high temperature extremes which the outer shell can safely withstand. There is no such liquid. Water is "incompressible" in such an application and has a low temperature coefficient, but its safe range is too short (possible damage by ice or steam). Mercury seems to be favored in the commercial instruments—no doubt because its expansivity is among the lowest. When it is used, the outer shell (the thermometric member) is made of steel or stainless steel.

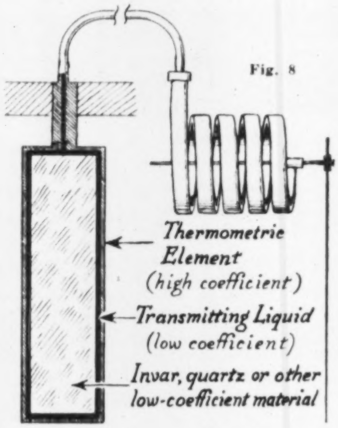

Thermometric Element (high coefficient)
Transmitting Liquid (low coefficient)
Invar, quartz or other low-coefficient material

Fig. 8

Speed of response is inversely proportional to thickness of outer shell. Industrial service conditions and actuating-power requirements (see Part 4) preclude the use of thin sheet steel (such as used in tin cans, for example) which would give as short a characteristic time as a bare-wire resistance thermometer. Nevertheless, the strong-shell instruments are two to six times faster than pressure-spring thermometers with bulbs having the same outside dimensions.

3. Bimetal Deflection Thermometers

The field of solid expansion thermometers today comprises few metal-and-refractory or two-metal-member devices. This field now belongs almost entirely to instruments employing single-member bimetallic elements. The manufacture of these elements has become a special industry because of growing demand for simple thermostatic devices mass-produced for household devices. Thus it has come about that the term "bimetallic thermal element" is being supplanted by the name of the product from which such elements are made—which is "thermostatic bimetal."

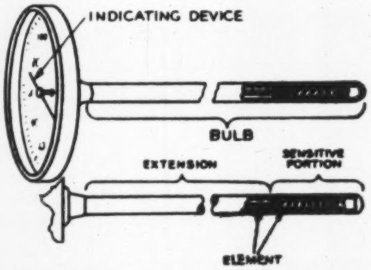


Fig. 9. SAMA's proposed standard terms for bimetallic thermometers.

Thermostatic bimetal is a metallurgical product made from two metals which have different temperature coefficients of expansion and which have been firmly bonded at their face of contact. When subjected to a change in temperature, the composite material will change shape, which change of shape is utilized for measurement and control purposes. In addition to having widely different coefficients of expansion, the components must have mechanical properties suitable to minimize hysteresis and provide adequate strength. (For example, lead cannot be used as a component.) The two component metals are usually of equal thickness and firmly joined before being rolled down to size.

The first known application of thermometric bimetals was in balance-wheel compensators, supposed to have been used in 1775 by the great watchmaker Abraham Louis Breguet, who later invented the *bimetallic spiral thermometer.* With the discovery by C. E. Guillaume in 1898-1899 of the low-expanding alloy known as invar, consisting of 36% nickel and the remainder iron, a new impetus was given the work on bimetals. A number of bimetallic-spiral thermometers appeared on the European and American markets.

***Especially for operating the position-balance type of transmitter, some forms of which exert a load on the moving member of the measuring system.**

**This combination is such a "natural" that it probably is being made; but the writer has not found it catalogued by any leading instrument company.

The effectiveness of a given bimetal depends upon the difference in thermal expansivity of the *two* components. Although numerous alloys now on the market have high expansivity, there are only a few alloys with expansivity nil or negative or at any rate sufficiently low for commercial use in bimetals.

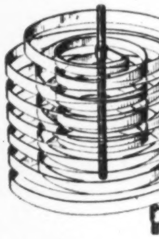


Fig. 10.

The original spiral elements have been giving way to *helical* elements in indicating and recording thermometers. One form of bimetal element consists (Fig. 10) of several concentric helices, so wound that their rotational deflection is additive while their axial displacement is mutually counterbalanced. These concentric helical springs are wound from a single strip of bimetal. This design permits the construction of thermometers of sufficient torque to provide deflection of a pointer over a scale long enough to be read to fractions of a degree, with a thermal element as small as the bulb of a glass thermometer.

The structural design of the great majority of bimetal elements is such as to produce a deflection—generally a rotation. In some applications, requirements call for a straight-line effect. A new form of element provides linear expansion and contraction from the bimetal element. In the manufacture of this unit, the narrow (approx. ⅛ in.) bimetal ribbon is wound in the form of a coil having the same outside diameter as the ribbon itself. The appearance of the helix at this stage is like that of a "spiral-wound" flexible armored cable. The next stage is to take a long length of this narrow coil, say 30 inches, and coil it into a helix which has an outside diameter of approx. ¾ in. but which is only approx. 2½ in. long. The final result of this process is a unit which has the property of expanding and contracting in a straight line coinciding with its own longitudinal axis.

PART 4

PRESSURE-SPRING OR FILLED-SYSTEM THERMOMETERS

1. General Characteristics

Pressure-spring thermometers ordinarily embody a system consisting of (1) a primary element in the form of a bulb, (2) a flexible capillary connecting tube and (3) a hollow pressure-responsive spring which moves the pointer or pen-arm (or which actuates the pilot or relay in a controller). Therefore they are sometimes referred to as "pressure gage" thermometers. The system contains a thermometric liquid or gas. The utilized temperature effect of this substance is always a pressure effect—even when its thermometric property is expansivity.

The universally accepted classification of pressure-spring thermometers is by the "filling" of the system. The original scheme (still used in some cases) was into three numbered classes. The usual engineering designation of these three classes has been "liquid expansion," "vapor-pressure" and "gas-filled." Without aiming to overthrow this classification into three classes, the author pointed out in 1930 the usefulness of recognizing that there are *four* classes. His reason—as valid now as in 1930—is as follows: The vapor-pressure systems and the gas-filled systems may each be conveniently described and studied as a class; but the "liquid expansion class" is different: with regard to applications, characteristics, limitations, etc., it really consists of two sub-classes, (a) mercury, and (b) liquids other than mercury. Such liquids *may* be various hydrocarbons, but xylene* has for some thirty years been used in most of the non-mercury liquid-expansion instruments in industrial use. The characteristics of the mercury instruments are so different from those of the xylene instruments that in undertaking to describe and tabulate the characteristics of pressure-spring thermometers it was found necessary to split up the old "Class I" and to publish the new "rational" division into four classes:

1. Mercury
2. Xylene, etc.
3. Vapor-Pressure
4. Gas

The fundamental operating principle employed in all four classes is the measurement of a pressure effect, by means of a pressure-responsive device. This device is unsuitable for ordinary volumetric measurements but its form is such that its internal volume increases as it uncoils. Therefore the entire system is not a constant-volume system.

The principal characteristics of the four classes are set forth briefly in Table III. Numbered notes pertaining to this table are added for the sake of amplification and clarification. These data are believed to satisfy all quick-reference requirements.

Outside of this table and the set of notes, however, a few general and specific statements remain to be made.

Pressure-spring thermometers possess one obvious advantage over the "industrial" and bimetallic thermometers which are local instruments: However inaccessible the point of application of the bulb may be (within tube-length limits), the "instrument" proper may be installed at eye-level.

Pressure-spring indicating instruments (dial thermometers) ordinarily are made up with one tube-system and one pointer; some may be made up with two pointers co-axial like the hands of a clock. Recorders are frequently made up with two tube-systems, sometimes with three or four. Dual-system or duplex controllers are regularly made up.

Centralization is made possible, for capillaries may be as long as 100 feet or more. Of course, the capillaries of pressure-spring thermometers must not be cut, whereas no permanent injury is done by breaking an electrical conductor. The entire tube-systems of pressure-spring recorders and controllers of some makes are removable, thereby lessening the "convenience handicap" in comparisons with electrical instruments.

The maximum length of the connecting tube is limited by the filling of the system and by the method of compensation for the tube errors, but there is no minimum length. Hence the popular "stem" forms of pressure-spring thermometers and the "room temperature" or "self-contained" recorders.

In addition to the information about scales in Table III, mention may be made of the possibility of *special scales* and *retard movements*. These are extremely valuable in connection with processes where the One Best temperature has been determined and is not subject to change. (Example, the pasteurization of milk.)

2. Implications of "Pressure-spring"

In considering the characteristics of the four classes and their relative suitability for various applications, it frequently is useful to think of the instrument proper as an ordinary Bourdon gage and to take into account its pressure range. Imagine a Bourdon gage graduated 0-30 psia. and calibrated for sea-level atmospheric pressure. At sea level it will indicate the true absolute pressure of any sealed container to which it is connected; if used in an airplane, its readings would have to be corrected for barometric error. (In fact, a gage of such low range could be used as an altimeter.) But if a Bourdon gage graduated 0-750 psia. is used on an airplane, the barometric difference between sea-level and customary ceiling will produce an error of less than 1% of its scale range.

Another example: Imagine a mercury-filled system consisting of bulb, 30-in. tube and pressure-spring, the spring being borrowed from the 0-30-lb. gage referred to in the preceding paragraph. In round numbers, the mercury-column equivalent for pressure is two inches of mercury per pound, or 30 in. mercury for the 15-lb. sea-level atmosphere. Therefore when the bulb of this system is at the same elevation as the spring, the gage reads 15; when the bulb is 30 in. lower than the spring the gage reads zero; when the bulb is 30 in. higher than the spring the gage reads 30. Substitute the high-pressure spring (0-750 lbs. or 50 atmospheres). Now the 60-in. difference between "bulb

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*Usually meta-xylene or dimethyl-benzene-*m*., $C_6H_4(CH_3)_2$; freezing-point —54°C., boiling-point 139°C. at N.B.P.

higher" and "bulb lower," which corresponds to two atmospheres, will cause the pointer to travel over only 4% of the scale range instead of 100%.

Still another example: The same mercury system, but with a gage having a scale range of 100 to 130 psi. (or 200-230, or 1000-1030 . . .). If the calibration pressure within the system is such that the gage reads zero with the bulb at the same level as the spring, the pointer will travel half-way across the scale when the bulb is raised 30 in.

Conclusion: the external and internal pressure errors are in inverse ratio to the "power" or stiffness of the springs. With sufficiently "powerful" springs, designed for *sufficiently long pressure ranges*, these errors may be made negligible.

This is tantamount to saying that a pressure-spring thermometer is a heat engine. An important characteristic of any system is the ability to do the WORK of driving a pointer or pen-arm over the requisite distance with sufficient force to minimize friction factors and other sources of error. With regard to pressure-spring thermometers the energy question is sometimes summarized by the assertion that the spring is "powerful enough" or "stiff enough." A more exact summarization is to state the rule that—

> *other things equal, the system producing the greatest pressure increment per unit increment of temperature is the most energetic,*

from which rule certain deductions and rough mental calculations can be made with the greatest of ease when comparative figures (on the various coefficients involved, etc.) are obtained. An example will be found several paragraphs below. Before coming to it, however, it is useful to set forth certain inherent operating characteristics of the four classes.

3. OPERATING CHARACTERISTICS OF THE FOUR CLASSES

I—ASSUMING A NEGLIGIBLY SHORT CAPILLARY

Mercury. The utilized thermal property is expansivity. Mercury has the LOWEST expansion coefficient of the liquids commonly used in pressure-spring thermometers: approximately one-seventh that of xylene. Therefore, considering only this expansion coeffi-

TABLE III—CHARACTERISTICS OF CLASSES OF PRESSURE-SPRING THERMOMETERS

CLASS	LIQUID-FILLED		VAPOR-PRESSURE	GAS
	MERCURY	"XYLENE"		
Filling	Mercury under initial high spring pressure (Note 2).	Xylene (or other hydrocarbon) under initial pressure	Volatile Liquid (Note 8)	Inert gas under moderate initial pressure
Scale	Uniform	Fairly uniform (Note 5)	Progressive (Note 9)	Uniform
Bulb Volume	Medium, and varies inversely with length of range	Small	Medium (Note 10)	Large, and varies with *Tube* length
Minimum Bulb Length	3 to 5 inches	1 inch	2 inches	5 inches
Bulb Material	Steel or stainless steel	Stainless steel, brass, Monel, or nickel	Brass, Monel, steel, silicon bronze, etc.	Brass, Monel, steel, silicon bronze, etc.
Average 63% response time (*L*) of average 7/16" diam bulb (Note 1) with rapid circulation	in water 5 sec. in air 60 sec.	in water 6 sec. in air 75 sec.	in water 4 sec. in air 50 sec.	in water 7 sec. in air 85 sec.
with slow circulation	in water 17 sec. in air 600 sec.	in water 20 sec. in air 750 sec.	in water 14 sec. in air 500 sec.	in water 22 sec. in air 850 sec.
Maximum Tube Length	25 feet (Note 3)	15 feet when uncompensated	250 feet (Note 10)	300 feet (Note 14)
Efects of temperature fluctuations along the capillary ("Tube error")	Vary with tube length and with area of capillary bore (Note 4)	Vary with tube length (Note 6)	None as long as bulb is hotter than tube (Note 11)	Vary with tube length and inversely with bulb volume (Note 15)
Can temperature fluctuations at spring be compensated	Yes	Yes	Compensation unnecessary (Note 11)	Yes
Effects of variations in atmospheric pressure (also "Altitude error")	Small (negligible in systems filled at high pressure)	Extremely small	Slight errors in lower end of range where actuating pressure is low	Slight errors at low working pressure only
Does different level of bulb and instrument affect calibration?	Yes	Yes—slightly (Note 7)	Yes (Note 12)	No
Lower limits of ranges	-38°C. or -36°F.	-100°C. or -150°F.	-180°C. or -300°F. (Note 13)	-240°C. or -400°F.
Upper limits of ranges	540°C. or 1000°F.	400° C. or 750° F.	370°C. or 700°F.	540°C. or 1000°F.
Usual maximum commercial length of one span	550 C.° or 1000 F.°	330 C.° or 600 F.°	160 C.° or 250 F.° (Note 13)	550 C.° or 810 F.°
Usual minimum commercial length of one span	25 C.° or 45 F.°	22 C.° or 40 F.°	50 C.° or 90 F.° (Note 13)	50 C.° or 90 F.°

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NOTES

(General Note)—Table III had to be compiled, in part, from information released for the first time by various qualified sources. No two sources agreed on all points.

(1) For capillary bulbs, about 0.25 of the value of *L* for a 7/16" bulb, plus a delayed start of about 0.1 *L* (see Chapter XII). All figures for *L* given here are rounded averages of widely-different values, especially for air.

(2) Comparative advantages of the high-pressure mercury filling are ruggedness, durability and permanent accuracy. A slight disadvantage is limited choice of bulb material.

(3) 150 feet or more when "full compensation" is used. One method uses a gas-filled capillary alongside the mercury capillary, this body of gas actuating a second pressure-spring, shifting the mercury mechanism to compensate for temperature fluctuations along the tube. In another method, the capillary tube is of high-expansion material, and has running throughout its length a wire of low-expansion material, so that for a given change in temperature, the change in mercury volume is the same as that of the annular space it can occupy.

(4) No effects when "full compensation" is embodied in the system.

(5) Non-linearity above 250°F. is slight and it is said to be the same in successive shipments of xylene accepted for fillings; therefore, printed recorder charts may be used.

(6) Slight: Even with smallest standard bulb, effect of change from ice to steam on 10 ft. capillary is claimed to produce 1°F. error in indicating bulb temperature. Some makers supply "full compensation" systems.

(7) Lowest working pressure, at low end of usual ranges, is 300 psi.; 10 ft. head of xylene = 3.5 psi.

(8) Characteristics of many volatile liquids being known, makers can supply proper filling for each range specified. It always is advisable to specify not only the range but the *zone* within the range where accuracy is most needed. Reason: sensitivity increases with temperature.

(9) A "progressive" scale is "closed" at its lower end and "open" at its upper end.

(10) The capillary and spring for the usual ranges are completely filled with unvaporized liquid, with vapor generated only within the bulb. If bulb is excessively small or if tube is excessively long, cold ambient temperature (reducing volume of liquid in tube and spring) would leave insufficient liquid in bulb where there must always be a free surface.

(11) In the usual arrangement, when any portion of the tube *or spring* is subjected to a higher temperature than that of the bulb, the pressure of the higher temperature is developed as long as there is any liquid exposed to the hot spot. See text.

(12) Considerably when working pressure differential is low. 10 ft. water head = 4.33 psi. Assuming a high Baume hydrocarbon, we get about 3.5 psi. for every 10 ft. Even more important is the total impairment of accuracy when bulb level is higher than spring and no liquid is left in bulb. Use of a transmission liquid sealed off from the active liquid by a bellows permits installing the bulb at a higher level than the spring. See text.

(13) Liquids are chosen which will produce a vapor pressure sufficient to assure fair sensitivity at lower end of specified range. The upper end depends on liquid's critical temperature and pressure.

(14) Fluid friction in the capillary is negligible, the medium being a gas, and the length limitation is imposed by the temperature errors. In plants provided with room temperature control, longer tube lengths may be used. Some makers supply "full compensation."

(15) The largest practicable volume of gas should be contained within the bulb and therefore the longest length which the applications can take should be specified, even where maker can supply "full compensation."

cient, the bulb length of a mercury system should be seven times the bulb length of a xylene system (having the same bulb diameter, the same range and the same internal volume of pressure spring) in order to produce the same uncoiling of the same spring for the same temperature rise at the bulb. However, this small expansion coefficient of mercury permits obtaining the same angular deflection from a much smaller spring. Moreover, the extremely small compressibility of mercury, and the wealth of accumulated knowledge of steel metallurgy, make possible *in actual practice* the manufacture and standardization of steel pressure springs of relatively small internal volume for relatively long total lengths of flattened tubing. The specific gravity of mercury is about 15 times that of most thermometric hydrocarbons. The two kinds of altitude errors would therefore be serious (as was explained above) if it were not for the possibility of using springs of adequately long pressure ranges. The scales of mercury systems are uniform, but over a long range (say 200 C. or more) mercury expansion departs slightly from the thermodynamic temperature scale law.

These are the GENERAL characteristics of the mercury class. Some commercially-available systems differ. Two may be mentioned:

(1) Instead of pure mercury, a mercury-thallium eutectic amalgam with low freezing point.

(2) A steel bulb almost completely filled by an invar cylinder; the mercury occupying the annular space between and used merely as a transmitting fluid, the steel bulb being the temperature-*measuring* element.

(This sub-type, though known commercially as mercury-filled, really belongs to the solid-expansion class.)

Xylene. In a xylene system the same principle of operation is used, but the properties of hydrocarbon liquids together with practical requirements of design and construction compel the use of relatively weaker springs. Uniform scales are provided; for most liquids used, the deviation of the expansion from the thermodynamic scale law is negligible.

Vapor-pressure. A vapor-pressure system makes use of the fact that the pressure in a vessel containing only a liquid and its vapor increases with the temperature and is independent of the volume so long as liquid remains. In this class of thermometer, therefore, the "strength" of the pressure-spring must be suited to the liquid and to the temperature range. The scale is "progressive"—which is desirable where one zone is of particular interest and where such zone can be the upper portion of the scale. Study Fig. 11. Note that the 0-350 F. scale (at the right) can be made as long *in inches* as the 0-250 scale, even if the same pressure-spring is to be used. This is done by adjusting the link ratios, etc. Note also that the spring (a stiff "thousand-pounder") will then be worked far below its elastic limit. On the other hand, when a low-pressure spring is used to suit the curve of a low-boiling-point (low-range) liquid, excessive pressure caused by exposure (of any part of the system) to excessive temperature would be injurious. This is true of all systems but the danger is greater with vapor-pressure systems as the shape of the typical curves shows. To prevent over-ranging, one maker employs an auxiliary bellows, "normally retained at a constant volume, but which is permitted to expand should the system pressure become excessive."

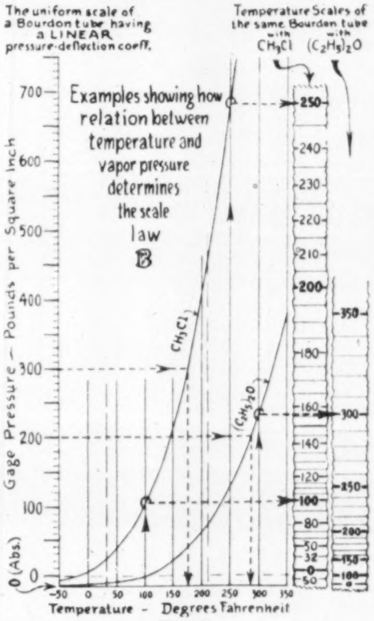

Fig. 11

These are the GENERAL characteristics of the vapor-pressure class. The commercially-available instruments really fall into four distinct subclasses or types, as explained in Fig. 12, which therefore should be studied in connection with the brief notes (10 to 15) in Table III.

Note particularly "Type D" in Fig. 12. It is the only simple and practical arrangement whereby the vapor-pressure principle can be utilized to measure bulb temperatures lower, higher (or equal to) the temperatures to which the tube and spring are exposed. Note the use of a non-volatile liquid (ideally, a non-thermometric liquid) as a pressure-transmitting medium.

Gas. The gas-filled systems utilize the simple relation which, for an ideal gas, is:

$$\text{Abs. Temp.} = \frac{\text{Pressure} \times \text{Volume}}{\text{a constant}}$$

and which is the basis of the constant-volume hydrogen thermometer formerly used for high-precision work. But the volume of a gas-filled system varies with the spring deflection. Moreover, hydrogen and helium (the "nearly perfect" gases) transpire through the pores of most bulb metals, especially at temperatures above the vapor-pressure thermometer range limit, often compelling use of "heavy" gases which deviate appreciably from the gas laws (though less than do liquid-expansion coefficients from linearity). The total deviation, in practice, is small enough for the instrument scales to be uniformly graduated. With regard to energy—to the work of driving the pointer

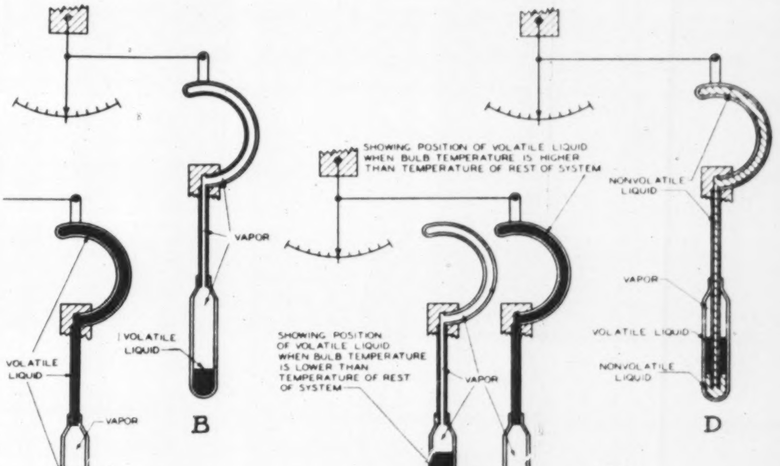
VOLATILE LIQUID
VAPOR
A
VOLATILE LIQUID
VAPOR
B
SHOWING POSITION OF VOLATILE LIQUID WHEN BULB TEMPERATURE IS HIGHER THAN TEMPERATURE OF REST OF SYSTEM
SHOWING POSITION OF VOLATILE LIQUID WHEN BULB TEMPERATURE IS LOWER THAN TEMPERATURE OF REST OF SYSTEM
VAPOR
C
NONVOLATILE LIQUID
VAPOR
VOLATILE LIQUID
NONVOLATILE LIQUID
D

Fig. 12. The four subclasses or types of vapor-pressure systems.

Type A is designed to operate with the measured temperature ABOVE the temperature of the rest of the system.

Type B is designed to operate with the measured temperature BELOW the temperature of the rest of the system.

Type C is designed to operate with the measured temperature above AND below the temperature of the rest of the system.

Type D is designed to operate with the measured temperature above, below and AT the temperature of the rest of the system.

or pen-arm—the gas laws provide two interdependent solutions of the problem, namely; make the bulb volume or the initial pressure, or both, as high as possible. The user can specify as large a bulb as the apparatus or pipe can take; the manufacturer provides the highest practicable *initial* pressure (pressure at the lower end of the scale range). The gas laws set practical limits to these interdependent solutions of the problem. Thus, in a system of the customary dimensions listed in catalogs, it obviously is impracticable to obtain adequate energy for complete travel across the scale from a 5-degree rise in temperature. That is one reason why gas-filled pressure-spring instruments are made up for relatively long temperature ranges: the longer the range, the stiffer the spring that can be used.

II—LONG CAPILLARIES

The foregoing discussion of characteristics has purposely considered the systems as consisting of bulb and spring connected by a capillary too short to be of consequence.

The increasing size of processing units, as well as the tendency toward centralized control in all industries and in public buildings, have not only made the "tube error" a factor of importance but have led to the embodiment of various ingenious schemes of "partial compensation" and "full compensation." The relative merits of various makes cannot be discussed here. Nor can even a small number of patented systems be shown in diagrams and their features discussed.

One method of full compensation employs a second pressure spring, the capillary tube of which runs the full length of the main capillary tube, stopping short at the bulb. The proportions, pressures, linkage design, etc., are such that a given change in temperature along the main capillary, producing a certain deflection of the measing element, produces also an equal and opposite effect on the pointer or pen-arm. The second capillary need not itself be a second *tube* enclosed in the outer protecting armor or flexible tubing: it may be the annular space between the transmission capillary tube and an outer tube.

Another system utilizes a capillary tube containing a wire. The tube is made of an alloy (a ferrous alloy for mercury) of relatively high expansion coefficient; the wire is made of one of the invar type alloys; the annular space between tube and wire is a capillary connection between bulb and pressure spring. This annular volume, therefore, has a *differential* coefficient of expansion which is designed to equal the expansion coefficient of the mercury, organic liquid or gas, allowance being made for pressure effects.

In the vapor-pressure systems, the tube errors are radically different—ambient temperature fluctuations causing temporary errors, as explained in the notes accompanying Table III. The principal source of error is generally caused by the absence of a liquid surface in the bulb, and this may occur not only by reason of long capillaries but even from failure to follow directions pertaining to position of bulb. The customary arrangement is simply to have the capillary extend into the liquid. Another (Type D in Fig. 12) uses a transmission liquid sealed off from the thermometric liquid selected for its vapor pressure curve. The sealing is effected by a flexible member, a *bellows* form being shown in the drawing. This permits the use of long capillaries because temperature fluctuations along the capillary or at the head of the system do not appreciably alter the characteristics. (The vapor-pressure principle, of course, is that the pressure of a vapor in contact with its liquid is independent of the volume.) The only possible source of error introduced by a sealing member arises from the fact that such a sealing member cannot be ideally slack. (We are not considering accidents such as leaks.)

Long capillaries may give rise to errors, at low regions of ranges, when the bulb and spring are at variably different elevations: the pressure at the spring is the algebraic sum of *vapor-pressure* in bulb plus or minus hydrostatic effect of *liquid*. Study Fig. 11.

4. MAXIMUM POSSIBLE PRESSURE INCREMENT PER UNIT INCREMENT OF TEMPERATURE AT BULB

This characteristic can be roughly calculated from the expansion coefficients of the liquid and of the bulb material, and the compressibility of the liquid, without need of putting into the equations the actual volumes involved, since these cancel out. The assumption is made that the bulb is subjected to a one-degree (C. or F. depending on the system of units) rise in temperature, and that the volume of liquid thereby displaced into the capillary is driven back into the bulb by the application of an external force to the pressure spring which causes it to recoil exactly as much as it had uncoiled. This gives the unit pressure increment and hence the energy factor for full deflection corresponding to total scale travel. This treatment is by no means rigorous, but the percent error in the final results remains practically constant in a series of computations, so that for *comparative* purposes this rough method will serve. For example, starting from the following data

Ratio of compressibility of mercury to organic liquid 3.7 to 145.

Ratio of expansion coef. of mercury to organic liquid 18 to 163.

Bulb material for each: steel exp. coef. in same units, 35.7.

we obtain 600 psi. for mercury and 150 psi. for the organic liquid considered in this example.

Using the Available Power. Having more power than other deflecting-member thermometers (except solid-expansion), pressure spring systems actuate with ease and without large error direct-writing recorders and practically all pneumatic and hydraulic controllers. (Electrical controllers usually impose no load at all on their measuring systems.)

Pressure-spring systems have ample power to actuate pneumatic transmitters and are being used more and more for that purpose even where the distances are not beyond the recommended limits for capillaries.

One type of pneumatic transmitter deserves mention because it minimizes the response times of relatively slow pressure-spring systems by use of a rate-of-change-responsive arrangement of bellows and restriction. This device is a combination of a force-balance 3-to-15-psi. transmitter and a derivative-action unit as used in many automatic controllers.

5. THERMOMETRIC LAG: COMPARATIVE "SPEEDS" OF THE FOUR CLASSES

A compromise must be made in practice between the requirement of a long pressure range for a conveniently short temperature range, and the wall thickness of the bulb. The greater the bulb-wall thickness, the greater the lag. Lag is objectionable when the bulb is the primary element of an automatic control system.

Since vapor-pressure systems must be designed with spring characteristics suited to the relation of temperature to vapor pressure of the filling, these systems are simply not used on applications requiring springs as stiff as those possible with mercury systems. In such applications, therefore, thin-walled bulbs may be used. Thus the general statement can be made that the vapor-pressure class systems respond more quickly than do the others. It must be emphasized that the reason does not lie in the inherent superiority of the vapor-pressure curve as a thermometric property of a substance.

The gas-filled systems, as actually manufactured, and considering the various design factors, are the slowest.

The mercury systems, as manufactured, are faster than the xylene systems as manufactured.

This simply means that, OTHER THINGS BEING EQUAL, the order of speeds of response is: (1) vapor-pressure, (2) mercury, (3) xylene, (4) gas.

But other things seldom are equal in practical industrial applications. A gas bulb immersed in circulating water will be about a hundred times faster than a mercury bulb in stagnant air. For measuring air temperatures, bulb shapes and sizes—rather than bulb fillings—are the deciding factors; and the choice will usually fall on a coiled-capillary bulb designed for the intended application, regardless of its filling.

The "Dip" Effect. When subjected to a sudden temperature change, most liquid-expansion thermometers momentarily indicate an opposite change—popular expression, "the mercury first goes down instead of up"—because the bulb proper (the metal or glass chamber) has responded almost completely before the contained liquid has hardly begun to respond. The maximum wrong-direction excursion usually amounts to about 10 percent of the sudden change and usually occurs less than a second after the sudden change; then the instrument's pointer or pen starts traveling in the right direction, crosses "zero," and continues rapidly in the right direction. The seriousness[*] of this "dip" is proportional to the thermal expansion coefficient of the bulb material: with fused quartz or Invar it would be negligible. This dip does not matter in the use of indicators or of slow-chart recorders, but it may cause a fast-response control system to do the wrong thing momentarily—the bad effect being more than momentary in some continuous processes where permanent damage is done to the quantity of product that flows during four or five seconds. (And in the case of milk and other food products the bad taste or the undestroyed bacteria may affect a much greater quantity of product.)

When subjected to a rapid (but not sudden) temperature change, an instrument subject to dip will have a longer response time than if the bulb were made of zero-expansion material. The more rapid the change, the worse the relative slowing down of the thermal system.

PART 5

RESISTANCE THERMOMETERS

1. CHARACTERISTICS

Electrical thermometers possess one important advantage: the primary element may be disconnected from the indicator, recorder or controller. Therefore a number of resistors ("bulbs") placed in widely separated locations may be successively connected to one electrical instrument. This centralization is of importance where comparisons of temperatures are desirable at a moment's notice.

It is also possible to obtain instruments so calibrated that direct readings can be taken showing either (a) the *average* temperature of two or more points, or (b) the *difference* in temperature between two points.

The lowest temperature accurately measurable with industrial forms of resistance thermometers is about ten degrees Kelvin[†] (-263 C. or -442 F.); the highest about 1000 C. (1800 F.).

Although pure platinum continues to be the standard for precision work, resistance elements with pure nickel or pure copper coils are much more widely used in industry today. Tungsten elements are now (1954) beginning to be used successfully. Semiconductors with enormous negative coefficients have appeared on the market (see Section 5). There has even appeared a liquid resistor—an electrolyte in thin tubing.

The intrinsic accuracy of the *metal* resistance thermometer is so high that under laboratory conditions the platinum resistance thermometer is used as the International Standard between -190 C. and 660 C., but a resistance thermometer is more "complicated" than a mercurial or pressure-spring thermometer and therefore industrial service may cause large errors through poor contacts, rough handling, deterioration or contamination of the platinum or other metal, defective insulation and other causes difficult to prevent altogether in plant service. In good hands and when the precautions recommended by the manufacturers are taken, the accuracy will be better than that of any other group of industrial temperature instruments.

Where accurate measurement of true temperature is necessary, as in calorimetry, determination of optimum process temperatures, etc., many engineers resort to the etched-stem laboratory thermometer immersed in a mercury well, sometimes forgetting that the mercury-in-glass method of thermometry is subject to numerous errors and requires corrections when *extreme precision* is required, whereas resistance thermometry would seem to be preferable, as will be seen by the following comparison:

1. *Stem Exposure*—The reading of a resistance thermometer with compensated leads depends only on the temperature of the coil and not on the temperature of the stem, provided that the immersion is sufficient to avoid errors due to conduction or convection along the stem.

2. *Aging effects* of mercurial thermometers arise chiefly from the small expansibility of mercury combined with the relative instability of the glass tube. In resistance thermometry, the effect of any possible strain of the wire of the coil is minimized. Zero creep of a resistance thermometer will be practically negligible, provided that the wire is not strained or contaminated.

3. *Pressure Correction*—The effect of change of pressure on a resistance element is negligible.

4. Finally, the speed of response of small-gage bare-wire resistance elements is much higher than that of other thermometer bulbs: characteristic times of the order of milliseconds are not extraordinary.

(On the other hand, bare wires must be used—and even *stored*—with extreme care.)

2. PRIMARY ELEMENTS AND "BULBS"

The operation of a resistance thermometer depends upon the variation with temperature of the resistance of an electrical conductor. The primary element, responding to temperature, is generally a resistance coil or spiral. This coil, together with its frame, tube and other necessary accessories, is itself called "the thermometer" in some publications, but the entire primary-element assembly may simply be called the "bulb."

For industrial service, the resistance coils are made of platinum, nickel, copper, or tungsten. In one form of 8-ohm platinum coil, fine wire is wound upon a frame made of crossed strips of thin mica notched at the edges to hold the wire in place. From the ends of this coil, lead wires of platinum or gold are carried to the terminal head where the binding posts are fixed. The lead wires are insulated and held apart by mica disks through which the wires are threaded, and which serve to minimize convection. The coil is protected by a porcelain or quartz tube which fits into the terminal. In another form, a 50-ohm coil of fine platinum wire is wound upon a fused quartz rod and fused inside a quartz tube, so that the platinum is entirely embedded in quartz. Gold leads are carried from the coil to the terminal head.

Nickel, copper and tungsten coils likewise must be protected from atmospheric or other contamination, from mechanical abrasion, and from severe vibration which may cause cold-working. The bulb assemblies for these three metals are almost always designed for industrial service rather than for highest-precision scientific work. What leading manufacturers strive for is *permanence* of calibration. Many inner assemblies are evacuated, filled with an inert gas such as helium, hermetically sealed, and encased in a rugged outer tube. Such bulbs are relatively slow (even when called "High-speed" in the sales literature): their response times are about the same as those of other primary-element assemblies whose outer tubes have the same *outside diameters.* The truly high-speed bulb assemblies are: (1) those with the smallest outside diameters, the thinnest outer shells, the fewest concentric envelopes and the least "dead-air" (gas) space; (2) the assemblies having the usual cylindrical terminal heads but with *flat* sensitive portions having large surface-to-volume ratios; (3) the new postage-stamp-size assemblies of resistance grids bonded in plastic, designed for studying surface temperature variations. But it cannot be repeated too often that speed of response depends mainly on the nature and circulation of the medium.

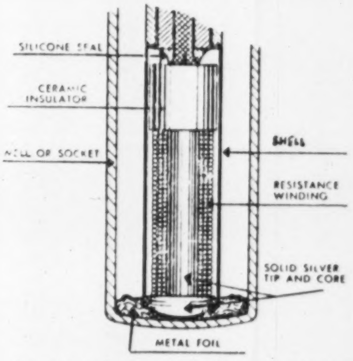

Fig. 13. Sectional view (about twice actual size) of an industrial resistance-thermometer bulb.

A great variety of primary elements for industrial applications is offered. Suitable bulbs are available for indoor or outdoor atmospheric temperature, refrigeration work, steam work, electric transformers, ovens, dryers, bearings, oil baths and other metallurgical applications, etc. Copper-nickel tubes,

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[*] Roughly, "seriousness" means maximum excursion multiplied by duration; exactly, it is the integral—the area between the curve and the initial-temperature line.

[†] This is with a special platinum assembly, helium-filled because the nitrogen and oxygen of an ordinary air filling would liquefy.

TABLE IV. QUICK-REFERENCE DATA ON RESISTANCE ELEMENTS

Material	Melting point (C.)	Usual range limits of commercial instruments Low C.	F.	High C.	F.
Platinum	1773	−263	−442	545	1013
Tungsten	3380	not announced		300*	572*
Nickel	1455	−190	−310	310	590
Copper	1083	− 40	− 40	125	257
Semiconductors	(various)	−100	−148	400	752

*For first commercially-produced bulbs; will be raised considerably before the next edition of this Handbook is issued.

round or flattened, are available for feed-water heaters or lines. Separable sockets or wells, in which a number of bulbs are interchangeable and which themselves have standard thread or flange connections, are used against corrosive conditions, against pressure up to 1500 psi. and higher. For surface temperatures "postage-stamp" elements with extremely fine wires combine convenience and relatively low cost with fast response. The new thermistors are already available in dozens of shapes, dozens of sizes and dozens of resistance values.

The commercially-available range of resistance values is likewise wide, satisfying the requirements of various electrical and electronic measuring instruments. In addition, some manufacturers of complete systems have adopted one cold-resistance value for their various styles of bulbs in order to make these bulbs conveniently interchangeable.

3. LEAD SYSTEMS

The following is a brief and excellent exposition from *Bureau of Standards Technologic Paper No.* 170:

If only two lead wires are carried from the thermometer coil to the indicator, the resistance measured is the sum of the resistance of the coil, the platinum or gold lead wires to the head of the thermometer,* and the copper lead wires from this point to the indicator. The resistance of the platinum or gold lead wires will depend upon the form of temperature gradient along the thermometer from the bulb to the head and upon the depth of immersion. Hence this variable resistance is introduced into the temperature measurement, and changes in the resistance of the lead wires will be interpreted as changes in the temperature of the thermometer coil. There are three general methods for minimizing or eliminating the effect of variation in lead resistance.

1. *Use of a Coil of High Resistance*—The resistance of the lead wires from the coil to the thermometer head and the variation in resistance of the copper lead wires are small compared to a 50-ohm platinum coil. Hence such variations in resistance as are likely to occur do not introduce serious error. Thus, only two lead wires are necessary, from the thermometer to the indicating instrument.

2. *Compensating Lead Wires of the Callendar or Siemens Form*—Both of these methods of compensation are applicable to measurements made with the Wheatstone bridge. The Callendar form of compensation requires four lead wires. Two of the lead wires joined to the end of the coil are connected in one arm of the bridge, and the other two lead wires, which are "dummy" leads formed of a single loop of wire extending to the top of the coil, are connected in the corresponding arm of the bridge. The two sets of lead wires are alike, so that variations in temperature affect each set similarly. The Siemens method of compensation requires three leads and is more often employed industrially.

3. *Potential Terminals*—The use of potential terminals is necessary when the resistance of the thermometer is extremely low or when the precision required is such as to make variations in difference of lead resistances inadmissible.

4. MEASURING SYSTEMS

The measurement of the temperature to which a resistance thermometer bulb is exposed is simply a matter of measuring its resistance. Practically, owing to the need of lead compensation, etc., the methods are limited to a few.

The simplest possible method, involving no lead compensation, is the familiar Wheatstone bridge, with the bulb resistor connected to the instrument by two conductors, the resistance of which is added to that of the measuring resistor. For descriptions of other circuits, the National Bureau of Standards is again quoted:

1. *Three-Lead Wheatstone Bridge Method.*—Fig. 14 illustrates the wiring diagram for a simple Wheatstone bridge and thermometer with the Siemens three-lead compensation. The platinum or gold lead wires $C'd$ and $T'e$ in the thermometer are constructed of as nearly the same resistance as possible and the copper lead wires CC' and TT' must also be of equal resistance. Battery B is connected between ratio arms r_1 and r_2 and to compensation lead wire cd. A sensitive galvanometer G is connected to points f and g, as illustrated. By changing r_3 the bridge is balanced until the galvanometer shows zero deflection. Whence from the principle of the balanced Wheatstone bridge we obtain the following relation:

$$\frac{r_3 + C'd}{r_1} = \frac{r_4 + T'e}{r}$$

If r_1 is constructed equal to r_2 then since $Cd = Te$, $r_3 = r_4$. Hence the measured resistance is independent of the resistance of the lead wires.

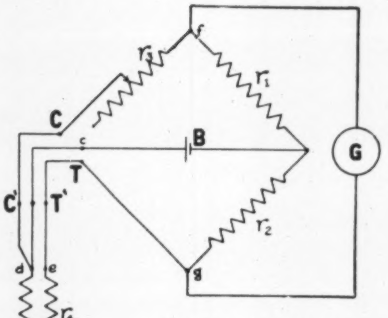

Fig. 14

2. *Four-Lead Potentiometric Method.*—Fig. 15 illustrates the wiring diagram for a four-lead thermometer used with a potentiometer. The current, adjusted to a suitable value by rheostat r_1, flows through resistance standard R and thermometer coil r_4. The potential drops across R and r_4 are measured by the potentiometer. Whence from Ohm's law, $e/R = e'/r_4$ where e and e' are the potential drops across R and r_4 respectively. Thus, knowing e, e', and R, the coil resistance r_4 is readily obtained. The resistance R may be made adjustable, so that by varying R until $e = e'$ the dial setting gives directly the value of $r_4 = R$. This method is useful in precise laboratory work.

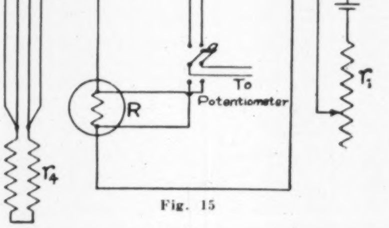

Fig. 15

3. *Deflection-Galvanometer Method*—(See Fig. 16.) With switch S thrown to the right we have the simple Wheatstone bridge, except that resistances r_1, r_2 and r_3 are fixed. At a certain temperature of the thermometer—for example, 10 C.—its resistance is such that the bridge is balanced and $r_3/r_1 = r_4/r_2$. If the temperature of the thermometer increases, its resistance increases and the bridge is no longer balanced. Thus a current flows through the galvanometer, producing a deflection. In general, the deflection of the galvanometer depends upon two factors—the temperature of the thermometer and the current flowing from the battery B.

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*In Bureau terminology "thermometer" refers to the element commonly called "bulb."

This current is adjusted to a definite value in the following manner: Switch *S* is thrown to the left, thus replacing the thermometer by a fixed resistance of such value that a suitable value of the current from *B* deflects the galvanometer to its full scale deflection or to a normal point marked on the scale. Resistance *R* is adjusted until the galvanometer deflects the proper amount. Switch *S* is then thrown to the right, and, since the factor of variable battery emf. or current is eliminated by this preliminary setting, the galvanometer scale may be empirically graduated to read directly the temperature of the thermometer. No further adjustments are necessary as long as this current remains at the proper value.

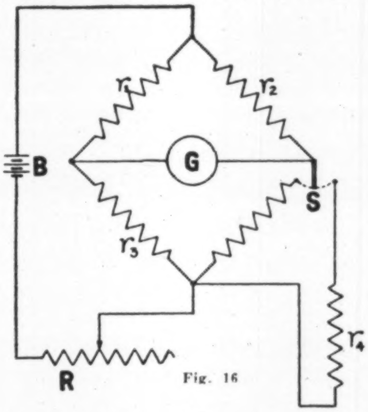

Fig. 16

It is possible to have two or more temperature scales on the galvanometer. When two scales are provided —as, for example, 0 to 300 C. and 300 to 700 C.—one of the arms of the bridge is made adjustable to either of two resistances, one giving zero deflection for a thermometer temperature of 0 C. and the other zero deflection for a temperature of 300 C.

For accurate results the four-lead system possesses the greatest adaptability, in addition to its obvious advantages as a measuring system. Nevertheless, the actual design and construction, and resultant characteristics, of commercially available instruments and accessories are factors of importance. There are recognized *grades* of resistors, as well as various ohmic values. Some standard resistors are made up in individual coils, each in a thermostated oil bath: they are replicas of the international standards. There are laboratory bridges, and there are inexpensive portable sets.

Types of Instruments. Industrial resistance thermometers may be classified by their forms, etc., but electrically they are all bridges; thus there are three types of equipment:

(1) "Unbalanced" Bridges: Deflection Methods. — Although the unbalanced bridge is usually condemned in electrical laboratory practice, it must be remembered that industrial temperature ranges are relatively short—which means an exceptionally short *resistance*-measuring range and nullifies most objections. Many instruments of this type are on the market. Those designed for industrial temperature measurements—and sold with a choice of primary elements and other accessories —represent specialized research and development; hence should be considered trustworthy.

(2) Null Method, Manually Balanced.—Most of these are the conventional table models, which are further subdivided into plug-out, decade dial switching, slide-wire, and combination. There have appeared also (a) portable outfits for industrial—rather than commercial — services; (b) switchboard models requiring no batteries and approximating the self-balancing instruments in other ways.

(3) Null Method, Automatically Balanced.—These are slide-wire bridges, designed for permanent installation, in which the galvanometer commands a servomotor-driven mechanism which restores balance and at the same time repositions the indicating or recording element. The parallel development of self-balancing bridges and potentiometers for industrial service has made available dual-function electromechanical assemblies which, considered as recording instruments, are practically identical whether for service as bridges or as potentiometers.

5. SEMICONDUCTOR RESISTANCE THERMOMETERS: "THERMISTORS"

Thermistor primary elements are dealt with separately because they differ from metallic resistance thermometric elements not only in their composition but in their *measuring properties*. Their six important properties pertaining to temperature measurement and control are the following:

1. Unlike metals, which are conductors, thermistors are semiconductors, the resistivity of the various commercial materials being 100 to 500 times greater than the resistivity of platinum. (The name thermistor means thermally-sensitive *resistor*.) Thermometric units are commercially available in resistance values from 10 ohms for a rather thick 1-inch disk to 50 megohms for various units—a typical one being a tiny bead sealed in glass with protruding leads—or even higher if desired. (These resistance values are at room temperature: 25 C. or 77 F.) The most obvious implication for measurement work is that the problems of lead resistance can be minimized by using high-resistance thermometric units

2. The temperature coefficient of resistivity of metallic-oxide semiconductors is negative: the resistance of a thermistor decreases as the temperature increases, whereas the resistance of a metallic coil increases with temperature. This property is of great usefulness as a means of automatic temperature compensation in electrical measuring instruments.

3. This coefficient is much greater than for metals. Whereas the resistance of a metal coil usually changes by about one-third of 1% per C. deg. of temperature change, the resistance of a thermistor may change by 6% or even by 8% per C. deg. of temperature change. This measuring property—high thermometric sensitivity—makes it possible to build long-scale short-range measuring instruments, which in turn suggests the possibility of tremendous advantages in automatic control of temperature. (But primary-element static sensitivity, though necessary for close control, is not sufficient.)

4. Whereas the temperature-resistance relations of metallic resistance coils are fairly linear (giving measuring-instrument scales that seem, at first glance, to be uniformly graduated), the temperature-resistance relations of thermistors are decidely curved. This large variation of the temperature coefficient of resistivity complicates problems of automatic temperature conpensation in electrical measuring instruments.

5. The heating of metallic resistance thermometer coils by the small currents flowing through them (for brief periods when at all) seldom presents serious problems. With thermistors, self-heating is a well-recognized characteristic—desirable in various types of circuit elements but highly undesirable in temperature measurement work. The safest rule for minimizing the I^2R error is not only to use a null method but to use an automatic self-balancing bridge with an operating cycle of a fraction of a second.

6. There is no getting around Nature's rules that good electrical conductors are good thermal conductors—and that electrical insulators are thermal insulators. The "thermometric speed" (thermal diffusivity) of semiconductors lies between that of thermal insulators such as mica or asbestos and thermal conductors such as metals. Its values vary with the materials and with methods of manufacture. For temperature recorders and controllers, the advantages of high static sensitivity of primary elements are lost if not accompanied by rapid response of these same primary elements. Therefore the sizes—or at least the thicknesses—of thermistors must be small; and the shapes must approach the ribbon or flake rather than the sphere. What is much worse is the effect of the combination of low thermal diffusivity with the peculiar self-heating characteristics of thermistors. In the first place, self-heating takes place throughout the body whereas cooling is from the surface, so that because of low diffusivity it takes many times longer for a thermistor to come to temperature with its surroundings, after a momentary surge of current, than it does for a metallic body of the same size and shape. In the second place, thermistors have peculiar power dissipation curves which render extremely difficult the problems of minimizing the resultant errors in temperature measurement practice, and which may play havoc in an automatic temperature control installation.

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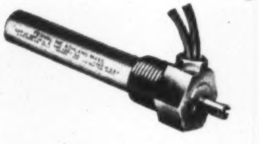

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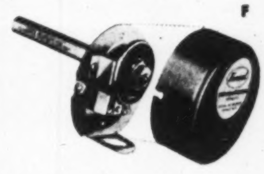

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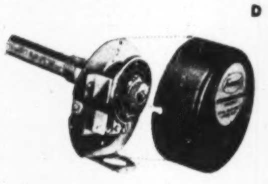

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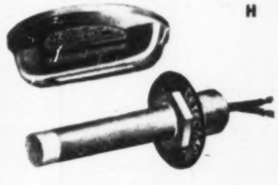

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D. Has conduit junction box attached. Threaded hexagon section permits immersion of brass shell in fluid through tapped hole or boss. Cover houses terminal block, dial and knob. Special units available with Underwriters' Listing.

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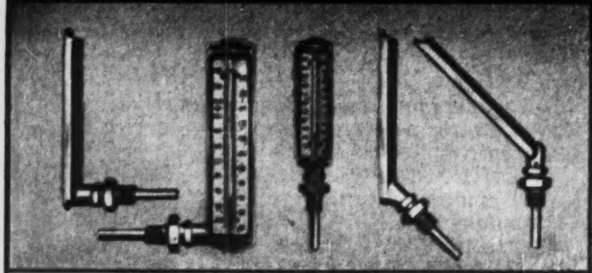

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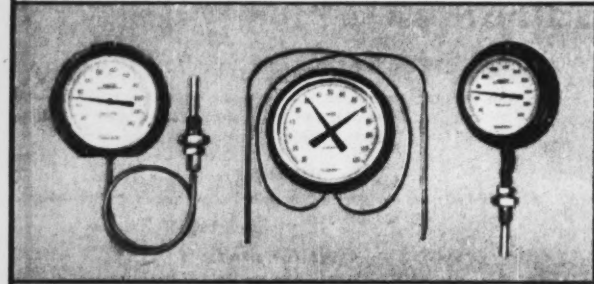

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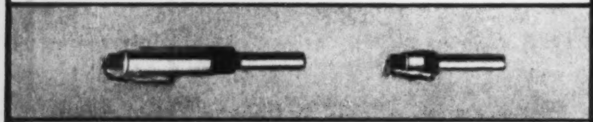

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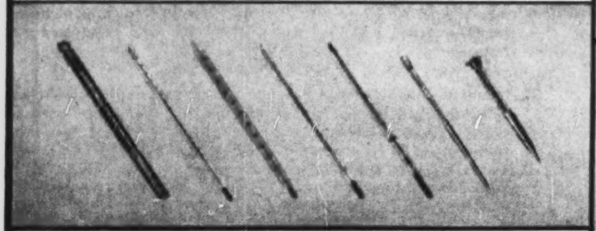

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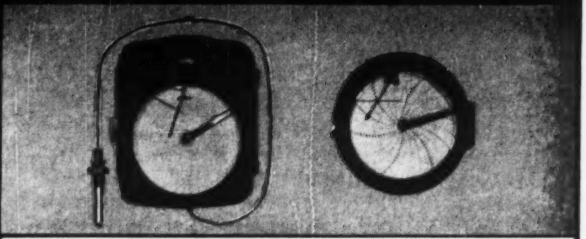

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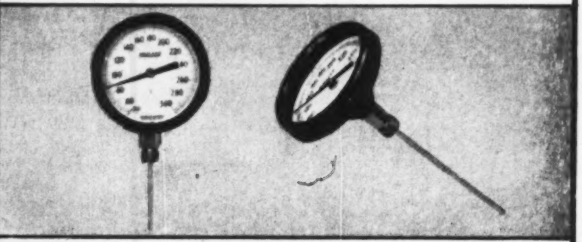

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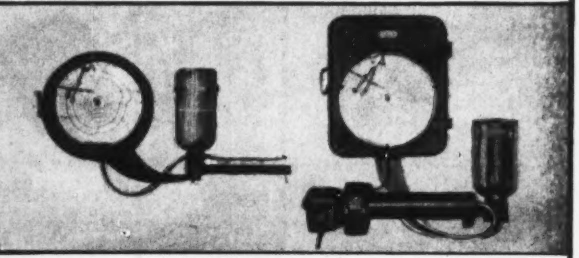

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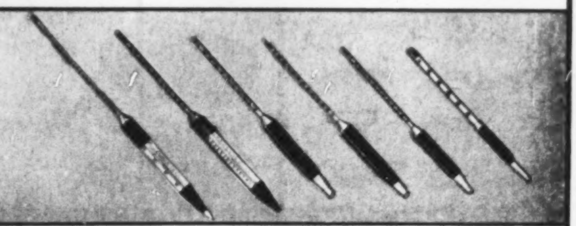

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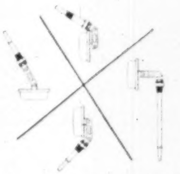

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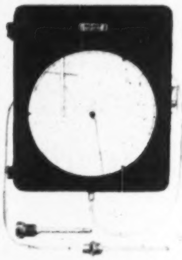
0+150°F	1°	0+400°F	5°	+200+750°F	5°
0+240°F	2°	0+500°F	5°	+200+950°F	5°

or equivalent °C—no extra charge



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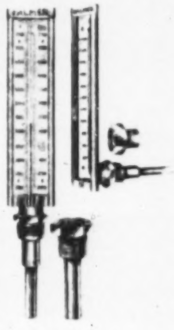

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FITTINGS: Fixed thrd., Union, Sep. Socket; adjustable or union Flange; parallel thrd. & locknut; special fttgs. to order.

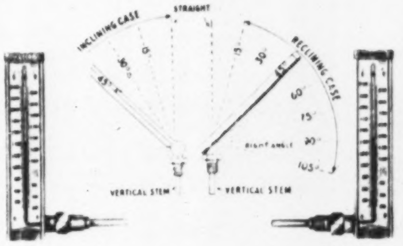
STEM: STRAIGHT and Misc. ANGLES. 3½" to 60", incl. thread.

THREAD: ¾" or 1" NPT (½" not recom.)

STANDARD RANGES:

−40+110°F	2°	+50+400°F	5°
0+100°F	1°	+100+550°F	5°
+30+180°F	2°	+200+750°F	5°
+30+240°F	2°	+200+950°F	5°
+30+300°F	2°		

Plain Mercury. Borosilicate tube. Centrigrade equiv.—no extra. Spec. Ranges—cost more.



Right Side

Left Side

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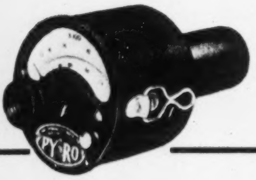

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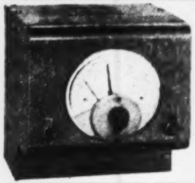

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CHAPTER II

PYROMETRY

By M. F. BEHAR

PART 1—COMPARATIVE CHARACTERISTICS

PYROMETRY and thermometry both mean measurement of temperature. The word pyrometry, from the Greek root for "fire," means the measurement of "high" temperatures, whereas thermometry refers to the measurement of "lower" temperatures. The accepted dividing line is "dull red," or about 1000 F.

An instrument capable of measuring both furnace temperatures and refrigerator temperatures can be called either a pyrometer or a thermometer, according to its application. The first industrial thermoelectric temperature-measuring instruments were pyrometers; and it became customary to call all thermoelectric instruments pyrometers. Today there are industrial thermoelectric temperature-measuring and -controlling devices usable to as low a temperature as −300 F. These are thermoelectric thermometers—not pyrometers.

Industrial pyrometers are usually classified as (1) thermoelectric, (2) radiation, (3) optical, and (4) fusion. The first three classes have pointer-and-scale displays, etc.; the fourth class comprises pyrometric cones. Each of the first three classes can conveniently be compared with the two others; but fusion cones constitute a separate class not subject to such comparisons.

The sensitive element of a thermoelectric pyrometer is immersed in, or in contact with, the body whose temperature is to be measured, whereas radiation and optical pyrometers are sighted from a distance. Therefore, in thermoelectric pyrometers, there is an essential element subject to deterioration.

With all thermoelectric pyrometers, and with *automatic* or *autographic* radiation or optical pyrometers, one can have temperature indications and records on panel-board instruments—including automatic controllers—and one can readily install multiple-switching arrangements. With a "hand" or "visual" pyrometer one can only measure the temperature of one thing at a time—the object sighted.

The conditions for high accuracy in the use of thermoelectric and optical pyrometers are fairly easy to realize; whereas invisible gases and vapors may seriously affect the readings of radiation pyrometers. Therefore, the latter are considered "less accurate" than the other two classes. Under standardized conditions, however, radiation pyrometers are as dependable as the others.

In each class there are both simple and complicated, robust and delicate instruments.

For measuring the temperature of objects having small mass (say a few cubic inches of a gaseous mixture, or a solid specimen the size of a pin) the ordinary industrial thermoelectric and radiation pyrometers can seldom be used; whereas most visual-optical pyrometers can readily be used if the body is incandescent. However, tiny needle-type thermocouples, originally developed for biological purposes, are now commercially available. But there are no industrial pyrometers for measuring the temperature of fast-moving objects such as projectiles. Nor are there any industrial pyrometers for FAITHFULLY recording (likewise without contact) temperature changes that occur in milliseconds.

Reference to Table I on page 25 (and to the quotation from the 1939 paper of which it was a part) **will show that possible solutions of all** these problems have long existed. For example **NO-CONTACT MAGNETIC METHODS permit measur**ing the temperature of a fast-moving strip or wire of any magnetizable metal or alloy in 0.01 second or faster. As far back as 1933 one such method was even tried for automatically controlling the temperature of a high-speed continuous furnace. Its success was advertised in 1934, together with the virtues of the razor blades made from the heat-treated strip; but the details of the no-contact magnetic method were not disclosed.

Industrial-type total-radiation receivers usually take several seconds (sometimes a minute or more) to come to equilibrium; but THAT situation looks more hopeful because the rapid-response infrared-sensitive photocell (see Part 5) has at last been commercialized.

Unlike other classes of pyrometers, *visual* optical pyrometers and *hand* radiation pyrometers require some skill of observation and sighting. It is possible, however, to sight radiation and *autometric* optical pyrometers by attaching them securely in one position at a definite distance from a peephole or refractory tube. A certain amount of skill is required when a permanent installation is made.

The maintenance required does not depend so much on the class as on the particular instrument and its auxiliaries. Experience and judgment are always required to detect and to remove causes of inaccuracy.

Causes of inaccuracy may arise within the instrument or from the installation. Eternal vigilance is required for continuously accurate measurements of high temperatures.

PART 2—THERMOELECTRIC PYROMETRY

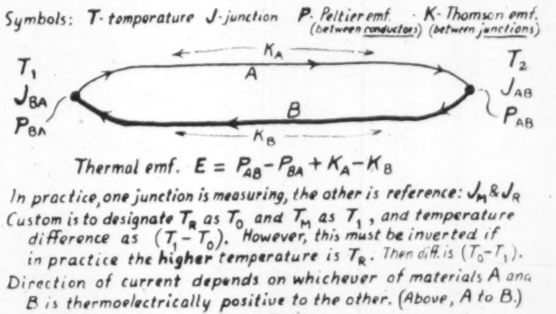
1. PRINCIPLES

When two conductors, made of different materials, are joined together as shown in Fig. 1, and when the temperatures of the two junctions are different, a current flows in this closed circuit.

An electric current usually flows by reason of a potential difference or electro*motive* force. In the simplest thermoelectric circuit (Fig. 1) there are no fewer than FOUR emf's. And the simplicity of electrical diagrams cannot be realized in practice. For example the simplest possible practical, usable thermoelectric pyrometer (a portable one of the "lance" form) requires a diagram like that in the center of Fig. 2.

In connection with Fig. 2 it may not be amiss to state that a THERMOCOUPLE is a pair of electrical conductors of dissimilar materials, designed and constructed for temperature measurement and control. The entire assembly, including protection tubes, etc., is generally called a thermocouple. A THERMOELEMENT is one of the pair of conductors, and the word thermoelements refers to the thermocouple proper. In discussions of characteristics, and in circuit diagrams, the word thermocouple (or "couple" for short) refers of course to the thermoelements.

The temperature effect utilized in thermoelectric pyrometry is an effect between bodies. It is not a static-electricity effect but a current-electricity


Symbols: T · temperature J · junction P · Peltier emf. (between conductors) K · Thomson emf. (between junctions)
K_A
T_1
J_{BA}
P_{BA}
A
B
T_2
J_{AB}
P_{AB}
K_B

Thermal emf. $E = P_{AB} - P_{BA} + K_A - K_B$

In practice, one junction is measuring, the other is reference: J_M & J_R
Custom is to designate T_R as T_0 and T_M as T_1, and temperature difference as $(T_1 - T_0)$. However, this must be inverted if in practice the higher temperature is T_R. Then diff. is $(T_0 - T_1)$.
Direction of current depends on whichever of materials A and B is thermoelectrically positive to the other. (Above, A to B.)

Fig. 1

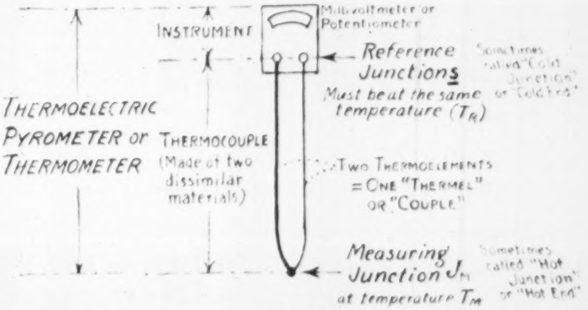

INSTRUMENT
Millivoltmeter or Potentiometer
Reference Junctions
Must be at the same temperature (T_R)
Sometimes called "Cold Junction" or "Cold End"
THERMOELECTRIC PYROMETER or THERMOMETER
THERMOCOUPLE (Made of two dissimilar materials)
Two THERMOELEMENTS = ONE "THERMEL" OR "COUPLE"
Measuring Junction J_M at temperature T_M
Sometimes called "Hot Junction" or "Hot End"

Fig. 2

effect. The ampere value of the current depends on the circuit resistance (Ohm's law). By using rods instead of wires, experimenters obtain thirty amperes of current, but the emf's are exactly those that would be obtained with hair-like wires. What depends on temperature is the *thermal emf.* It usually is a millivoltage.

The thermal emf. (also called Seebeck emf. after its discoverer) is always the resultant of *Peltier emf's* AT junctions, and of *Thomson (or Kelvin) emf's* BETWEEN junctions. A Peltier emf. is an emf. seated in one junction, and varying with the temperature of this junction. A Thomson emf. is distributed along a conductor and is always associated with a temperature gradient between the two junctions terminating this single conductor, so that it varies chiefly with the difference between the temperatures of these two junctions, but it varies also with the temperatures of the junctions and with the temperature distribution along the conductor.

The Peltier emf. varies with the absolute temperature of the junction where it is seated. The formula is $P = TdE/dT$. The manner in which the Thomson coefficient varies (the "law" of this effect) has not yet been determined. The value of a Thomson emf. can only be determined by experiments involving Peltier emf's, and by mathematical computations which need not be gone into here. The only mathematics needed in practice is the familiar memory-aid, "Seebeck equals Peltier plus Thomson." The "plus" means, of course, the *algebraic sum.*

A thermoelectric pyrometer is, in one sense, a reversible heat engine—though a poor one. Thermal energy flows from hotter portions of the system to colder portions, and some of it is transformed into electric power which an instrument (itself essentially a "motor") then transforms into the mechanical power that deflects a pointer. It is impossible, however, to use a homogeneous electrical conductor as a heat engine which takes in thermal energy and gives out a thermal emf. actuating a motor or instrument. Therefore, a thermocouple wire can be tested for homogeneity by connecting its ends to a zero-center galvanometer and subjecting various portions of the wire (except the ends near the instrument) to temperature gradients. Any deflection of the galvanometer, in either direction, will be a sure sign of inhomogeneities.

It is impossible to use a *single* junction of two dissimilar materials as a heat engine which takes in thermal energy and gives out a thermal emf. actuating a motor or instrument. The contact potential at a single junction (which can only be measured by special laboratory apparatus) is not the Peltier emf. The Peltier emf. arises from the fact that thermal energy enters a junction from the environment, causing electric energy to cross the junction in one direction; or heat passes from the junction to the outside, causing electricity to cross the junction the other way; AND that the "mirror image" of this process goes on at a SECOND junction symmetrically associated with this first junction. Therefore, an instrument "reading" obtained with a thermocouple open is a sure sign of stray currents, wires touching, voltaic emf's due to chemical action, etc.

The conclusion is that even the simplest possible thermoelectric circuit (Fig. 1) consists of TWO heat engines; the Peltier effects engine and the Thomson effects engine—one in which heat travels horizontally with temperature; and one in which heat travels vertically across the temperature *gradient* of the first engine—of course from a hotter to a colder region in each case. *Neither of these thermoelectric engines can exist without the other.*

2. Measuring the Thermal Emf.

For each class of industrial thermoelements the relation of temperature difference to thermal emf. is accurately known. The National Bureau of Standards has published tables of values. Good practice consists in measuring *this thermal emf.*, and doing our best to avoid measuring anything else. It would be simple if we could have a MEASURING circuit consisting only of two wires as in Fig. 3, with no discontinuity of any kind except at the two junctions. Since this is not the case in practice, good results depend on being able to distinguish the thermal emf. from all error-causing emf's.

The simplest MEASURING circuit usually comprises the following components: (a) The thermocouple, inserted where the temperature is to be measured and embodying the measuring junction, which is generally at the tip. (b) The reference junction, which usually is not one but two connections—between each of the thermocouple wires (or their extension leads) and copper leads or brass terminals. (c) Some provision for either keeping the reference junction at a constant temperature, or for automatic compensation for variations in reference-junction temperature. (d) An electrical instrument for accurately measuring the comparatively feeble emf. (e) Various appurtenances such as insulation, protection tubes, terminal heads, etc.

The simplest measuring circuit, Fig. 4, differs considerably from that of Fig. 3. In the first place an instrument has been inserted in series, increasing the circuit resistance. Therefore, the current due to the thermal emf. is decreased. Its value in milliamperes is no longer the thermal emf. in millivolts (E) divided by the thermocouple resistance in ohms. It is $E/(R_{TH}+R_{INS})$. And the potential difference across the instrument terminals is not E but

$$E \times R_{INS}/(R_{TH}+R_{INS}).$$

In the second place the series instrument is a milliammeter without a shunt, used to measure millivoltage. Its temperature readings will be affected by variations in external circuit resistance.

In the third place we have three thermocouples instead of one. Reading clockwise, these are B to A, A to brass, brass to B. In order to introduce no errors, the two binding posts MUST be maintained at the same temperature.

Now we generalize this case and derive a rule applicable to all thermoelectric pyrometer circuits.

The preceding discussions have brought out that certain types of circuits will not, and others will, generate thermal emf's; also that a thermoelectric circuit, reduced to its essentials, is symmetrical. Everything comes in pairs: materials, temperatures, temperature gradients, potentials, emf's, and so on. Some pairs are vertical, other horizontal. There is about it a useful symmetry which, if kept in mind, enables the user to take proper precautions while not wasting time and effort on unnecessary precautions.

What we call the Law of Symmetry is but a new name for a series of well-known (but heretofore uncoordinated) directions to users, laws of thermoelectricity, etc. The simplest statement of this law would involve descriptions of thermoelectric circuits producing *one* thermal emf. which depends upon the difference between T_M and T_R and upon nothing else. This law is expressed graphically in Fig. 5. If the axiom that equal and opposite effects cancel out is borne in mind, three things can always be done:

1. In making an installation or in using a self-contained outfit, the correctness can be verified. See Figs. 5 to 11.
2. To an existing circuit there may be added various features, provided only that each addition does not constitute a source (or sources) of spurious emf's. An alteration will generally change the total circuit resistance, but this in itself does not change the *thermal* emf.
3. From the circuit DIAGRAM of an existing installation there may be eliminated all features which do NOT contribute error-causing thermal emf's—all features in which contacts are clean and in which the junctions of dissimilar materials are known to be at the same temperature. (The elimination can consist of pencil lines drawn around such error-free features, one by one.) Then the trouble-shooter, without having to tear down a lot of wiring, can proceed to check one by one the components, conductors, connections, etc., that really deserve suspicion.

The Law of Symmetry implies that altering a thermoelectric circuit means introducing two or more junctions. Think of each pair of additional connections as a pair of thermoelements when the materials are dissimilar—and make sure that the effects are equal and opposite. Similarly, in any *single* conductor, any contamination or other cause of inhomogeneity will al-

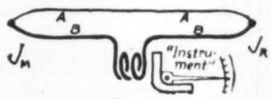

A
B
A
B
J_M
J_R
"Instrument"

Fig. 3.

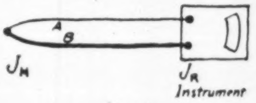

A
B
J_M
J_R
Instrument

Fig. 4.

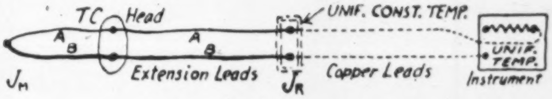

TC Head
UNIF. CONST. TEMP.
A
B
A
B
J_M
Extension Leads
J_R
Copper Leads
UNIF. TEMP.
Instrument

Fig. 8.

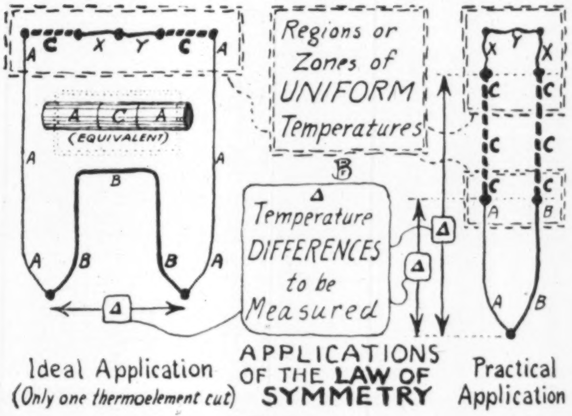
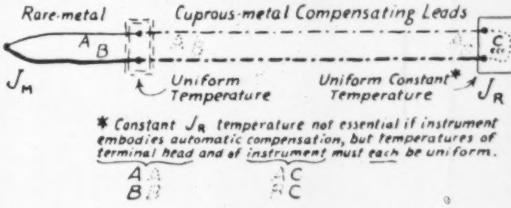

C
X
Y
C
A
A
A
C
A
(EQUIVALENT)
A
A
B
A
B
B
A
Δ
Regions or Zones of UNIFORM Temperatures
Δ
Temperature DIFFERENCES to be Measured
Δ
Δ
X
Y
X
C
C
C
C
C
C
A
B
A
B
Ideal Application
(Only one thermoelement cut)
APPLICATIONS OF THE LAW OF SYMMETRY
Practical Application

Fig. 5.


Rare-metal
Cuprous-metal Compensating Leads
A
B
C
J_M
Uniform Temperature
Uniform Constant* Temperature
J_R
A
B
C
C

* Constant J_R temperature not essential if instrument embodies automatic compensation, but temperatures of terminal head and of instrument must each be uniform.

Fig. 9.

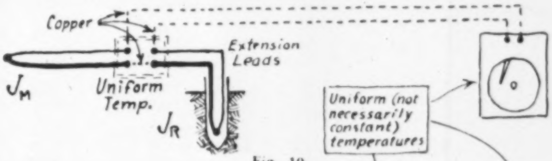

Copper
Extension Leads
J_M
Uniform Temp.
J_R
Uniform (not necessarily constant) temperatures

Fig. 10.

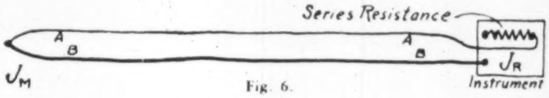
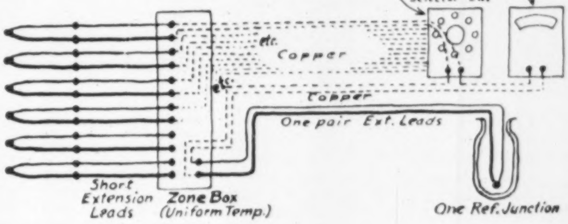

Series Resistance
A
B
A
B
J_M
J_R
Instrument

Fig. 6.


Selector Sw.
etc.
Copper
etc.
Copper
One pair Ext. Leads
Short Extension Leads
Zone Box (Uniform Temp.)
One Ref. Junction

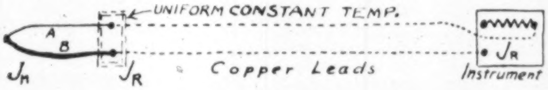

UNIFORM CONSTANT TEMP.
A
B
J_M
J_R
Copper Leads
Instrument

Fig. 7.

Fig. 11.

ways introduce *two* additional junctions. Thus, if we represent the homogeneous material by *A* and the contaminated section by *a*, the effect will always be

$$AAAAA \underset{J}{|} aaaaaa \underset{J}{|} AAAAA$$

Reference is made to a contaminated *section*. A tiny inhomogeneous spot caused by one drop of perspiration would seldom create an emf. because its ends would be at the same temperature. But exposure to furnace and other atmospheres causes sections to be contaminated and exposed to temperature gradients, whence—always—emf's causing errors.

The simple pyrometer shown in Fig. 4 (a pair of thermoelements attached directly to a millivoltmeter) can be used for precision measurements of temperatures only when the millivoltmeter has automatic compensation for reference-junction temperature. When the millivoltmeter cannot be located near the terminal head of the thermocouple, the lengths of lead wires between the thermocouple and millivoltmeter can vary in resistance and thus introduce errors.

One solution to the problem of long lead wires is to insert, in series with the couple, a resistance so much larger than the *changes* in lead-wire resistance that the variations become negligible. See Fig. 6. The series resistance, or *ballast*, usually is made of manganin, which has a negligible temperature coefficient of resistivity.

When the extension leads are of materials different from those of the thermocouple materials, additional Peltier and Thomson potentials are introduced. For rare-metal couples, extension leads can be made of pairs of inexpensive materials, the temperature-emf. characteristic of which is practically the same as that of the couple. Such leads are called *compensating leads*. Since their composition is not exactly the same as that of the couples, they are not true extension leads and their two connections to the rare-metal wires must be kept at the same temperature.

A typical compensating-lead circuit is shown in Fig. 8: The instrument contains not only the series resistance but the reference junction and also a mechanical or electrical arrangement which obviates the need of keeping the reference junction at a constant temperature.

The types of lead wire commonly used with typical thermocouples are shown in Table I. As copper, constantan, and iron are inexpensive, the lead wires are of the same material. For thermocouples of more expensive materials, low-cost lead wires of proper temperature-emf. characteristic are used.

TABLE I—THERMOCOUPLE LEAD WIRES

Thermocouple +	*Thermocouple* −	*Lead wire* +	*Lead wire* −
Copper	Constantan	Copper	Constantan
Iron	Constantan	Iron	Constantan
Chromel	Alumel	Chromel	Alumel
Chromel	Alumel	Iron	Copper-nickel alloy
Platinum-rhodium	Platinum	Copper	Copper-nickel alloy
Chromel	Alumel	Copper	Constantan (to 125 F. only)

Line-resistance Compensation

It has been shown that one way to *minimize* errors caused by fluctuations in line resistance due to temperature fluctuations is to use high-resistance measuring instruments. It often is advisable to take care of *all* changes in line resistance which occur in service. One way to do this is to measure the line resistance from time to time with a Wheatstone bridge, and to correct faulty conditions as detected. This method is not "compensation." There are two methods of compensation:

(1) The *adjustable-series-resistance method* uses an instrument with an adjustable rheostat. The rheostat is calibrated for a new installation of the thermocouple and leads. The adjustable resistance is reduced when the line resistance increases; the line resistance is measured by a portable test set.

(2) The *Harrison-Foote method* obviates the need of a separate test set by using a built-in arrangement of resistances, one of which is adjustable and in series with the line and measuring instrument. This resistor is set at its maximum value when the instrument is calibrated. When the instrument is used, the series resistance is adjusted to give a predetermined reading on the instrument whenever

a push-button (or key) is in either of its two positions. It is checked in a similar manner. This device is useful for multiple installations which have different line resistances. As many series rheostats are used as there are thermocouples, and each is adjusted in the manner described.

Reference-junction Compensation

Any uncompensated variation in the temperature of the reference junction causes a corresponding error in the indication of the pyrometer. As with the line-resistance variation (which is less serious) two methods are available for eliminating reference-junction effects: (1) hold the reference junction at a constant temperature, or (2) let it fluctuate but compensate for variations.

If the reference junction is to be kept at a constant temperature, it must be moved away from the vicinity of the terminal head. For checking and testing purposes in the plant, and for scientific work in the laboratory, a thermos bottle filled with cracked ice is best because it gives the ice-point reference and makes possible the most accurate work. For some installations the reference junction can be inserted in a pointed pipe driven 10 or more feet into the ground. See Fig. 10. Thermostat-controlled heated boxes are also in use.

There are two methods of compensating for variations in reference-junction temperature—manual and automatic.

For *manual compensation* the circuit is opened, the pointer or pen-arm is set to read the temperature of the reference junction, which is usually that of the instrument, and the circuit reclosed for work. The instrument temperature is room temperature (except when the instrument is carelessly located) but, in order to eliminate guesswork, a simple thermometer may be included in the instrument.

Automatic compensation is obtained in many different ways in the laboratory, but in the plant there are three important methods—(1) mechanical, (2) magnetic and (3) electrical.

The *mechanical method for automatic compensation* interposes a bimetallic spiral between the moving coil of the millivoltmeter and the pointer or pen-arm. When the circuit is open, the reading is the reference-junction temperature. This method compensates not only for cold-junction variations but also for the temperature coefficient of the instrument itself, which results mainly from changes both in spring strength and in resistance of the copper of the moving coil. It is of course impossible for the bimetallic coil to compensate exactly for both.

The ingenious *magnetic shunt method for automatic compensation* is simply a small block of iron on a thermostat spring, which tends to proportionately shunt the magnet poles of the instrument as the temperature varies. The shunting affects the field strength and hence the effective coil torque.

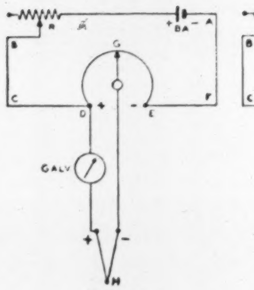


Fig. 12

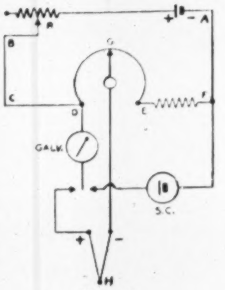


Fig. 13

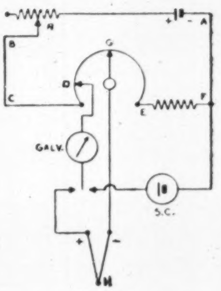


Fig. 14

The *electrical method for automatic compensation* uses an auxiliary bridge circuit, which contains a compensating coil of material having a large temperature coefficient. The resistance changes of this compensating coil, which is located in the reference-junction zone, alter the balance of the bridge, causing the current from a dry-cell battery connected across the bridge to correct the thermocouple emf. electrically in accordance with the changes of the reference junction. The temperature-responsive coil and the reference junction are both located at the instrument. A rheostat in the battery circuit is used periodically to adjust the battery current. A switch connection permits checking the rheostat adjustment by using the pyrometer millivoltmeter to measure the battery adjustment to a check point on the scale.

Another automatic method for electrical compensation of reference-junction temperature utilizes a simple series resistor made of a material with a *negative* temperature coefficient of resistivity.

With or without cold-junction compensation, it is necessary to maintain the cold-junction terminals at the same temperature. When an instrument with automatic compensation is exposed to heat such as radiation from a furnace, the terminals outside of the instrument case can attain a different temperature from that of the compensator within the case. This produces an error.

The Potentiometer

For precision work the potentiometer is a better measuring instrument than the millivoltmeter. It is more sensitive and its sensitivity is adjustable. Even more important, the potentiometer makes it possible to measure the potential developed by the thermocouple regardless of the variations in circuit resistance, length of leads, and other electrical conditions which may affect the reliability of millivoltmeter readings, especially after months of severe service.

The *null potentiometer circuit* compares the unknown potential with a known potential, which is calibrated against a standard cell. Resistances in the circuit are adjusted until there is a negligible flow of current at the moment of measuring. In a *deflection potentiometer* a part of the potential is balanced out and a part measured in the usual way.

As a potentiometer circuit requires little current flow—and no current when balanced—it is unaffected by resistance changes of the thermocouple and its leadwires. For applications where variations in external circuit resistance cannot be avoided, and where accuracy to 1 percent of the instrument scale range is desired, the potentiometer should be used.

Electrically, there are three types—the true potentiometer, the semi-potentiometer, and the deflection potentiometer.

Structually, there are three types also—bench (with or without galvanometer and other features), portable, and switchboard.

Simple potentiometer circuit (Fig. 12)—The unknown potential developed by thermocouple H is connected to the circuit at points D and G. Point G is a movable contact on a slidewire resistor, DGE. Battery BA produces a potential drop across resistor DGE. This potential has the same polarity as the thermocouple potential. Movable contact G is moved along the slide-wire resistor until the potential drop produced by the battery across DG is exactly equal to the potential developed by the thermocouple. At this point no current flows in the thermocouple circuit through the galvanometer, just as no current flows through two batteries of equal potential when they are connected in parallel. At the balance point the galvanometer needle shows no deflection.

The accuracy of measurement depends on the accuracy with which the potential developed by battery BA is known. A standard cell is added to the circuit, as shown in Fig. 13, for standardizing the battery potential. The standard cell produces a highly accurate and constant potential. This potential is connected to the potentiometer circuit at points D and F by means of the switch shown below the galvanometer. Variable resistor R then is adjusted until the potential developed from D to F by battery BA just equals the potential of the standard cell, as indicated by a balance of the galvanometer. This adjustment of the potential of battery BA is done periodically. The standard cell is disconnected from the circuit after the adjustment

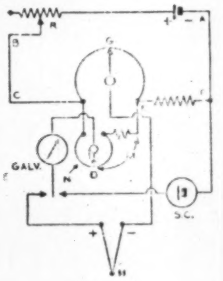


Fig. 15

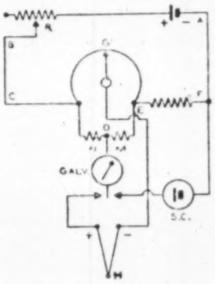


Fig. 16

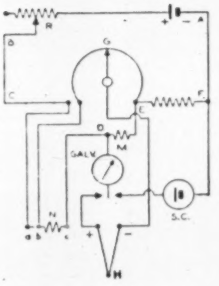


Fig. 17

and the thermocouple is reconnected to the potentiometer circuit.

Reference-junction compensation.—The balancing potential is developed across resistance DG. If point D is made movable, as shown in Fig. 14, the potential DG can be varied at either D or G. Therefore, compensation for reference-junction changes can be done simply by setting slider D at a point that corresponds to the known temperature of the cold junction. The potentiometer then is balanced in the conventional manner by slider G for making temperature measurements. The readings obtained by slider G then give the temperature of the hot junction directly and accurately.

The same result can be obtained by connecting point D to a second slide-wire resistor, which is in parallel with the main slide-wire resistor, as shown in Fig. 15. This second slide wire has a temperature scale. Manual compensation for cold-junction temperature is done simply by setting point D to the temperature of the instrument, as indicated on the scale.

Note that moving contact D either increases potential N and decreases potential M, or decreases N and increases M. In other words, the ratio of potential N to potential M is varied. In indicators and recorders with automatic cold-junction compensation, the ratio of N to M is varied automatically as shown in Fig. 16. Point D is fixed between two coils, M and N. Coil M is a constant-resistance coil with a low temperature coefficient of resistivity. Coil N is a nickel coil located at or near the cold junction. As nickel has a high temperature coefficient of resistivity, the ratio of M to N varies with the temperature of the cold junction, thus automatically providing cold-junction compensation.

Fig. 17 shows a modification of the automatic-compensation circuit that permits the cold junction (and coil N) to be located at a distance from the measuring instrument.

Accuracy of potentiometer circuits.—The accuracy attainable with a potentiometer depends on the accuracy of the reference standards used in the balancing technique. In the potentiometer circuit there is (1) the ultimate reference standard, which is the potential of a standard cell, (2) the working standard, which is the periodically-adjusted potential from a battery or other source, and (3) the resistors that balance the potentials.

The *standard cell* is a small voltaic cell of the cadmium type, usually made in the form of an H. The potential of a standard cell is slightly more than one volt, the exact value being certified to 0.1 millivolt in industrial models. Some industrial potentiometers use other sources for a standard reference potential.

The *resistors* used in the potentiometer circuit can be as precise as the price, size, and weight of the instrument permit. Accuracy to the fourth decimal can be realized in expensive thermostated oil-bath models.

Although the more expensive bench-type potentiometers used in the plant calibrating room can be made reasonably free from the effects of spurious potentials, this is not true of the less expensive portable and switchboard instruments. Portable potentiometers must be small and light. Switchboard instruments usually have motors, lamps, electron tubes, etc., within their cases, which evolve heat and cause temperature *gradients*. The effect of spurious potentials can be reduced by keeping the many junctions at uniform temperature.

The *galvanometer* is a seldom-seen component of a potentiometer or bridge. Designed for switchboard service, it is small, rugged, stable, and sensitive. Its function is to detect the unbalance in the potentiometer circuit. Some industrial potentiometers use other unbalance detectors.

Semi-potentiometer

In the semi-potentiometer no current flows at the time a measurement is made, but the value of the potential to be measured is read from a deflection instrument in the circuit. As in the conventional potentiometer, the thermal emf. is balanced out by a potential from a reference source, and the balance indicated by a galvanometer. The opposing potential, which then equals the thermal emf. because couple and lead-resistance factors disappear, is read directly on a millivoltmeter. The advantage of the circuit is that no current flows at the time of measurement. The attainable accuracy, however, is limited by the accuracy of the deflection instrument.

Deflection Potentiometer

In null-method potentiometer circuits, no current flows at the moment of measurement. In order to convert a null-method potentiometer into a deflection potentiometer, the galvanometer is balanced and the center of its scale is marked for the temperature at which the circuit is balanced. The scale of the galvanometer is then calibrated on both sides of the center in degrees of temperature by referring to the curves of thermal emf. vs. temperature, which the National Bureau of Standards publishes for each type of thermocouple. The scale can thus be made to cover a range of less than ten degrees, depending on the sensitivity of the galvanometer movement. This instrument, with a scale calibrated in degrees, is called a deflection potentiometer.

3. THERMOCOUPLES

There is a trend toward standardization of thermocouples because a few industrially successful thermoelements have emerged as industry's favorites while others have been relegated to unusual applications. However, the variety of mechanical construction of mountings and accessories grows greater with almost every new catalog. This is a healthy situation because there is a pleasantly wide choice of constructions for all important applications and a growing number of "specials," each made to order for some industry or standardized piece of equipment. These "specials" include complete indicating systems, quantity-built and assembled, consisting of thermocouple, cable, and millivoltmeter indicator, all ready to use.

Every pair of thermocouple materials has limitations as well as advantages. Interchangeability is essential so that the instrument scale will not need recalibration each time a couple is replaced. The elements on the market are standardized and almost perfectly interchangeable within each type. Because of this, commercial instruments have indicating scales and recording charts which are graduated in degrees of temperature, and which read correctly for particular types of thermoelements. The most common thermoelements are classified as either rare-metal or base-metal couples.

Rare-metal couples are made of platinum and platinum with rhodium. The platinum-rhodium alloy is available in two compositions: (1) 90 percent platinum and 10 percent rhodium, and (2) 87 percent platinum and 13 percent rhodium.

Base-metal couples are usually iron-constantan, chromel-alumel, or copper-constantan. Other combinations of base metals are being used also.

The *graphite to silicon-carbide* couple was developed for the pyrometry of liquid iron and steels.

The temperature-emf. characteristic of common thermocouples are shown in Fig. 18. The principal service characteristics are shown in Table II.

A couple suitable for use in oxidizing or reducing atmospheres at "safe" temperatures should be used in either, but not in one after having been used in the other, whatever the temperatures of the first and second.

Rare-metal Thermocouples.—Although the first cost of rare-metal thermocouples is several times that of base-metal couples made of wires of same gages and lengths, rare-metal couples are seldom more expensive in the long run. The reasons are practical rather than theoretical. In the first place, their outstanding reproducibility and stability permit their being selected for applications where extreme accuracy is required and where, consequently, precautions are not overlooked. In the second place, their chief weakness (silicon contamination) is so well-known that precautions are redoubled. Thus it frequently is reported that the cost per furnace per year of using rare-metal couples is smaller than for furnaces where base-metal couples are used.

The chief limitation of rare-metal couples is that they require special protection, particularly in reducing atmospheres. Silicous materials must be avoided.

Rare-metal couples are frequently used bare in the laboratory, but both thermoelements are so easily contaminated that extreme precautions must be taken. When contaminated, they can in many cases be restored to good condition. A publication of the National Bureau of Standards gives directions for removing some surface impurities, restoring homogeneity of microstructure, and so forth.

Maximum deviation from the two standard curves recognized by all manufacturers is seldom more than 5 F. at 2000 F. for new rare-metal couples. Such an "error" is not even observable on the scale of an ordinary millivoltmeter pyrometer. As a rule, a new rare-metal couple can confidently be used in the plant without checking by the plant instrument department.

A rare-metal couple and a high-grade portable potentiometer can be used as a portable temperature checker, just as an inspector's gage which is taken around to check ordinary pressure gages. However, note that the temperature reading given by any couple (when reference-junction precautions are observed) is the temperature of its measuring junction, so that with different protections and different immersions, two perfect couples can give widely different readings of the same furnace temperature.

Iron-constantan.—Supplementing the Table II recommendations under "Iron-constantan" is the following statement to the author from Dr. I. M. Stein:

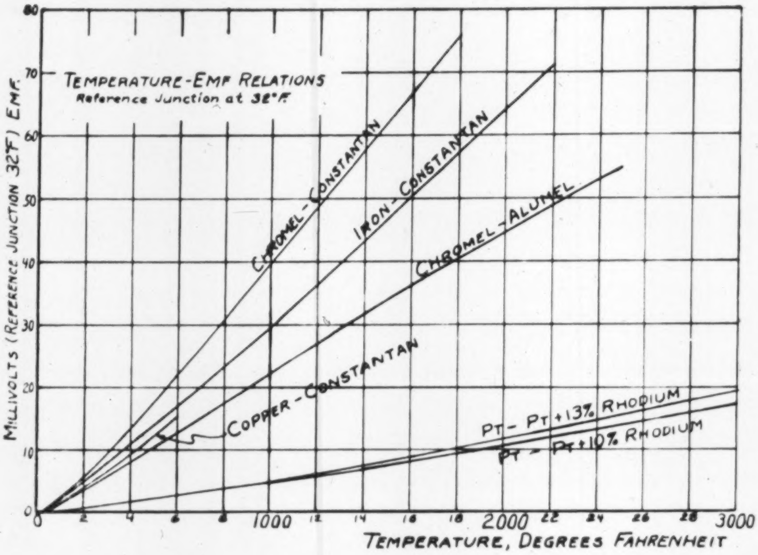


Fig. 18 (*Drawn by W. C. Stickney*)

TABLE II—PRINCIPAL CHARACTERISTICS OF THERMOELEMENTS

Where two temperatures are given, higher is for thickest wires and lower is for thinnest wires commonly available. Degrees are FAHRENHEIT

Couples	*Pt* / *Pt Rh*	*Copper* / *Constantan*	*Iron* / *Constantan*	*Chromel* / *Alumel*	*Chromel X* / *Capel*
Lowest temp. for satisfactory results (1)	32°	Approx. −400°	Approx. −400°	Approx. −400°	Approx. −400°
Highest temp. for good results; BARE couple in air	———	350° to 560°	600° to 1300°	1200° to 2000°	600° to 1000°
Highest temp. for good results; BARE couple in molten metals	———	———	600° to 1200°	1000° to 2000°	———
Highest continuous temp. for good results, usual protection (2)	2400° to 3000°	350° to 650°	700° to 1500°	1400° to 2200°	700° to 1100°
Reproducibility (3)	Excellent	Depends on 'constantan'	Depends on Sources	Excellent	Fair
Resistance to corrosion (normal use)	Perfect	Fair	Fair	Good	Good
Resistance to oxidation at highest temp.)	Perfect	Fair	Fair	Good	Good
Standard diameters of wires	B.S. gages 30 to 20	B.S. gages 36 to 2	B.S. gages 32 to 2	B.S. gages 30 to 2	B.S. gages 30 to 2
Especially useful for	Standards and precision work	Low temperature	———	Oxidizing atmospheres	
Not recommended for	Use with silica tubes	———	———	Reducing atmospheres	

(1) Thermocouple tip being measuring junction; and reference junction the hotter of the two.

(2) Temperature of the elements—not necessarily temperature to be controlled. See text.

(3) Reproducibility or interchangeability—Uniformity of electrical characteristics in order that successive purchases of wire will have same characteristics.

> ". . . A correct statement of the situation cannot be made quite so briefly, but we shall attempt to give you our ideas as briefly as possible.
>
> "1. The ironconstantan couple used under proper conditions gives a more reliable relation between emf. and temperature than any other type of base-metal couple.
>
> "2. In an oxidizing atmosphere, particularly at temperature above 1400 F., the life of an iron-constantan couple is much reduced so that for such services the chromel-alumel couple is usually recommended in spite of its less reliable temperature-emf. relation.
>
> "3. In some reducing atmospheres, the iron-constantan couple theoretically would be subject to errors due principally to the action of the constantan. However, the reducing atmospheres that are usually encountered in practice are of such nature that the iron-constantan couple is not appreciably affected and is the one usually recommended for reducing atmospheres."

In 1940 it was pointed out that there was an enormous difference between the temperature limits recommended for the smallest and heaviest wires. This has been incorporated in Table II. This difference is greater for iron-constantan than for any other pair of industrial thermoelements.

Copper-constantan.—This couple is not recommended for temperatures above 600 F., because copper oxidizes too rapidly, although it is suitable for both reducing and oxidizing atmospheres. Interchangeability between different couples and from lot to lot can be guaranteed within smaller limits than other base-metal couples—about 6 F. Frequently this type is used with multiple junctions, i.e., several couples in series, for work in small areas where quick readings are desired. At the low temperatures for which this couple is suitable, no primary or secondary protection other than insulation is ordinarily required. When used in acid fumes or under other corrosive conditions, a thin-wall transparent quartz-glass or hard-porcelain tube is adequate protection.

Chromel-Alumel.—Best service is obtained when used in oxidizing atmospheres. Interchangeability from element to element and lot to lot, is generally guaranteed within 15 F. The somewhat lower degree of interchangeability of these as compared with iron-constantan is in part offset by the fact that they can be used for a higher temperature range. Some manufacturers have recommended this type for temperatures as high as 2400 F. This is possible for short periods only, even with the heaviest wires.

Miscellaneous Notes on Thermocouples

Cold-working alters the curve of most elements. Swaging, bending, and twisting the wires nearer the weld do not matter so much as sharply bending a portion which will be exposed to a temperature gradient. The steepest gradient, of course, is at a furnace wall. Therefore, even double-protected couples must be handled with this in mind.

Remember that for an equal exertion of finger-muscle strength, the area stresses in a small-gage wire are much greater than in a heavy wire; also that the seriousness of "surface" impurities is in inverse ratio to diameter.

As the potentials are millivolts, it is essential to use clean contacts and high-grade switches to prevent variable-resistance errors and other sources of erratic readings.

The reference junction is usually two junctions (element A to brass, brass to element B). The same condition may apply to the hot junction. Its wires need not touch if they are immersed in molten metal, or rubbed and pressed hard against a metal surface. There are many uses for a bare couple. For temperature of solid metal parts (bearings, etc.) the wires may be peened into the metal. In such cases the two wires should be close together because a difference of temperature at their respective entrance points will set up an additional emf. In all such cases, too, it should be noted that the surface temperature is the one which will be indicated. Welded or twisted couples dipping in slightly conductive liquids should not be immersed deeply.

Radiation and conduction always affect the readings of couples. The couple develops the emf. due to its own temperature, but its own temperature may be different from that of the medium. The wires conduct not only electricity but heat. Where a high order of accuracy is desired in measuring furnace atmosphere temperature, the couple tip should be surrounded by a sleeve to prevents its "seeing" surfaces colder or hotter than the atmosphere. This prevents radiation to or from such surfaces.

Protection Tubes.

For high-temperature work the protecting tubes are of greater practical importance than the thermoelements.

The following properties (as listed by the National Bureau of Standards) should be considered in reference to the particular process for which the tube is required:

(1) Low porosity to gases. Many tubes become porous to furnace gases at high temperatures.

(2) Low volatility. Certain metal tubes are undesirable at high temperatures because the metal distills upon the couple, thus altering its calibration.

(3) Ability to withstand high temperature.

(4) Ability to withstand sudden changes in temperature.

(5) Ability to withstand mechanical shocks and strains.

(6) High rigidity. Protecting tubes frequently deform and exhibit the phenomenon of plastic flow at high temperatures.

(7) Thermal conductivity. High thermal conductivity is frequently desirable when rapidly changing temperatures are measured. Usually, however, low thermal conductivity is desired so that the flow of heat along the tube is as small as possible.

(8) Ability to resist corrosion from molten metals or furnace gases.

4. MAINTENANCE FACTORS

The most common cause of errors in the use of thermoelectric pyrometers is *poor connections*—loose, corroded dirty, oily, and so forth.

The next most common cause of error is *short-circuits* inside thermocouple stem caused by worn or broken insulators. Other causes are:

(1) Locating instruments too near sources of heat. Even automatic compensation of cold junction in instrument case may not be designed to take care of serious increase in coil resistance (and hence lower torque) due to excessive temperature. No compensation is designed to nullify the effects of gradients in the instrument case.

(2) Locating instruments where they are subjected to excessive vibration and shocks. A sudden jar can cause two or more turns of a spiral spring to catch one another. This shortens the spring which opposes the coil and readings will be too high.

(3) Inadequate protection from dust, fumes and moisture.

(4) Altering length of extension and even of copper leads.

(5) "Repairing" broken or worn extension leads with unsuitable wires. This can cause an error of 15 percent of range.

(6) Even in replacing compensating leads with properly chosen new leads, reversing polarity will cause errors.

(7) Various unforeseen causes of change of lead resistance.

(8) Running leads close to furnaces for long distances. As commercial wiring is not perfectly homogeneous, the variable resistance causes errors unless a true potentiometer is used.

(9) Neglecting to check with open circuit.

(10) Neglecting to periodically verify temperatures of buried cold junction.

(11) Neglecting to inspect thermostated junction or zone boxes.

(12) Neglecting to test contacts of multiple and other switches.

(13) Variable immersion of thermocouples.

(14) Allowing ashes, dust, clinkers or other material to accumulate on the end of the protection tube.

(15) Using instruments calibrated for one type of thermoelements to measure temperature with a different type of couple.

(16) Impairment of homogeneity of thermocouple wires where exposed to temperature gradients. Such impairment is usually caused by contamination (cracked protection tube, etc.).

(17) Induced currents, stray leakage, etc. Wherever there are electric furnaces, electrical machinery or even the usual plant wiring, in the close vicinity, the original installation should be made by a trained man. This is especially true of multiple-switching circuits.

(18) Voltaic effects arising from worn insulation plus moist wood, etc., between leads of dissimilar materials.

(19) The "Becquerel effect," set up sometimes when tubes are not gas-tight and themselves emit a gas which contaminates the couple. This is sometimes remediable by annealing the wire.

(20) If the pointer wobbles, there is trouble somewhere—probably a loose connection or defective insulation. Sometimes the trouble can be located by shaking one part of the circuit after another.

PART 3—TOTAL-RADIATION PYROMETRY

1. LAWS AND DEFINITIONS

All bodies not at absolute zero temperature—and not tightly blanketed, i.e., “in the open”—constantly emit electromagnetic radiation to their surroundings.

All bodies constantly absorb electromagnetic radiation from their surroundings, if not shielded therefrom.

Electromagnetic radiation comprises all wave-lengths from the extremely short-wave secondary cosmic rays to the longest radio waves. Theoretically, one body of any size or material would continuously emit all the wave-lengths of this entire spectrum if its temperature were high enough, but some physicists believe that only the hottest stars do so continuously, and there is some doubt that even a nuclear-fission bomb does so momentarily. It has been known for centuries that common objects at the temperatures of molten lead, tin or zinc do *not* emit visible radiation—and the expression “red heat” came to mean the temperature at which most ordinary objects begin to glow visibly. (It is about 980 F.)

The electromagnetic radiation which is emitted by a body *solely because of its temperature* is variously known as total radiation, or thermal radiation, or radiant energy—or radiant heat (to distinguish it from light which of course is a form of radiant energy). In pyrometry, thermal radiation is preferably called RADIANT FLUX, a term having a precise meaning, which is *power*. Radiant heat is a form of energy; its common units are the erg and the joule. Radiant flux, being radiant energy in transit, is a form of power; its commonly used unit is the watt.

According to some workers, Radiation Pyrometry should cover the design and use of all “distance” pyrometers, including those which depend entirely on the human eye and therefore can only be used to measure the temperatures of bodies that emit light.

In practice, the “radiation pyrometers” are generally understood to be those that respond to all wave-lengths of radiant flux; and the “optical pyrometers” those that utilize only narrow bands of wave-lengths in the visible spectrum. Another simple way of putting it is to say that radiation pyrometers are NON-SELECTIVE or TOTAL-RADIATION instruments; whereas optical pyrometers are SELECTIVE. (More about this in parts 4 and 5.) What is important to bear in mind is that an ideal radiation pyrometer in perfect condition is a total-radiation receiver which converts radiant flux into a thermometric Utilized Effect, thereby MEASURING the temperature of the source upon which it is sighted. Therefore, any factor such as dust, dirt, intervening medium, etc., or any condition within the instrument itself, which cuts down the radiant flux or makes the instrument “selective” (instead of “total”) will cause serious errors.

The radiant flux emitted by an “ideal” body—known as a BLACKBODY—is *exactly* proportional to the fourth power of the absolute temperature of this body.

A blackbody is one that absorbs all—and reflects no portion of—the radiant flux which falls on it. A piece of black velvet, perfectly black to *luminous* flux, may reflect a large portion of *radiant* flux. On the other hand, a small opening in the wall of a cold furnace is a true blackbody which absorbs all the wave-lengths of radiant energy as well as all the wave-lengths of visible radiation. Conversely, when the furnace is hot, such a small opening radiates as an almost-perfect blackbody and makes an excellent source for radiation-pyrometry purposes.

When two ordinary bodies—common objects—face each other, each radiates to the other. The NET transfer of radiant energy from the hotter body to the colder body, per unit of time, is roughly proportional to the fourth power of the difference in the absolute temperatures of the two objects. For two blackbodies it is EXACTLY the fourth power.

This fourth-power relation is known as the Stefan-Boltzmann Law. It makes possible the accurate measurement of temperature when source and receiver are both nearly-perfect blackbodies (and when the intervening media do not absorb an appreciable amount of radiant flux).

Fig. 19 gives quantitative values of the rate of thermal-energy radiation per unit surface of a blackbody source. This rate, known as RADIANCY and measured in watts per square centimeter, may be likened to the brightness of a luminous source. It is proportional to the fourth power of the temperature of the radiant source, as is evidenced by the slope of the straight line in Fig. 19. Thus at 2000 degrees Kelvin (2000 C.Abs. or 1727 C.) the radiancy is 16 times what it is at 1000 K. (Incidentally, by converting from Metric to English, it is seen that at 2000 K. or 3141 F., a blackbody radiates nearly one horsepower per square inch.)

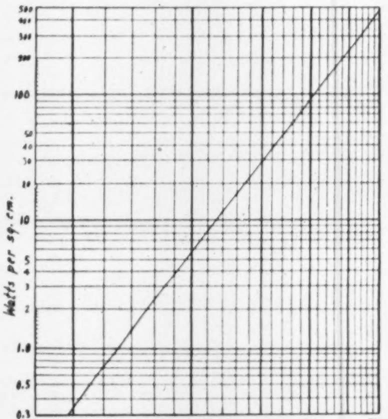


Fig. 19

Another phenomenon observed for centuries is that the color of an incandescent object changes with its temperature: “dull red,” “cherry red,” “bright red,” “orange,” “straw,” and “white hot.” In familiar radio vernacular: not only does the area under the wave-length curve broadcast by a glowing body increase according to the fourth-power law, but the center of gravity and the peak of this curve both shift toward the shorter wave-lengths with increasing temperature. The shift is known as Wien’s Distribution and Displacement Laws, which state: (1) that the radiant energy per unit wave-length interval at the peak varies as the *fifth power* of the absolute temperature and (2) that this maximum-intensity wave-length is inversely proportional to the absolute temperature of the blackbody source. This is shown graphically in Figs. 20 and 21, where other numerical consequences of these laws are lettered-in.

The shape of the thermal radiation curve—the *spectral radiancy distribution curve*—was determined exactly by numerous experiments begun more than a hundred years ago, but all attempts to formulate its equation failed until Plank announced in 1900 his quantum theory of radiation emission and absorption; and not until 1905 to 1915 did Einstein develop his photon theory of radiation and show that quanta were not mathematical conveniences but realities. Experiments proved that radiant heat and light are made up of Einstein’s photons; and in 1939 Haas announced that the photon content of blackbody radiation varies as the *third power* of the source temperature.

2. PRINCIPLES OF INSTRUMENTAL MEASUREMENTS

The foundations of radiation pyrometry are firmly established; the physical constants used in primary-instrument calibration are known to the fourth decimal. Theoretically, with this accumulated knowledge, a blackened-bulb thermometer installed in front of a furnace peep-hole could be calibrated as a radiation pyrometer without depending on any other pyrometer for measuring the furnace temperature at each calibration point. Practically, this would take a roomful of instruments, a month’s time, and perhaps some “guesstimating” of properties of materials—and then the calibration would be made worthless if someone pushed the bulb slightly out of place or altered any other calibration condition.

Essentially, a radiation pyrometer is a simple instrument. See Fig. 22. Its functions, however, are to receive an exactly-limited continuous sample of radiant flux from the source, to focus this continuous sample upon the RECEIVER PROPER (or “sensitive element”)—which is a small *blackened* body (a perfect blackbody being impracticable), and to measure the heating effect of the radiant flux. These functions are ex-

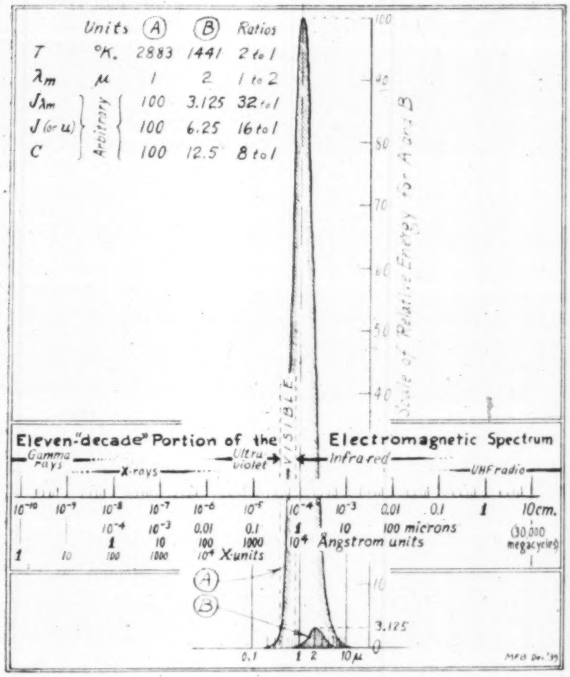


Fig. 20
Logarithmic wave-length scale

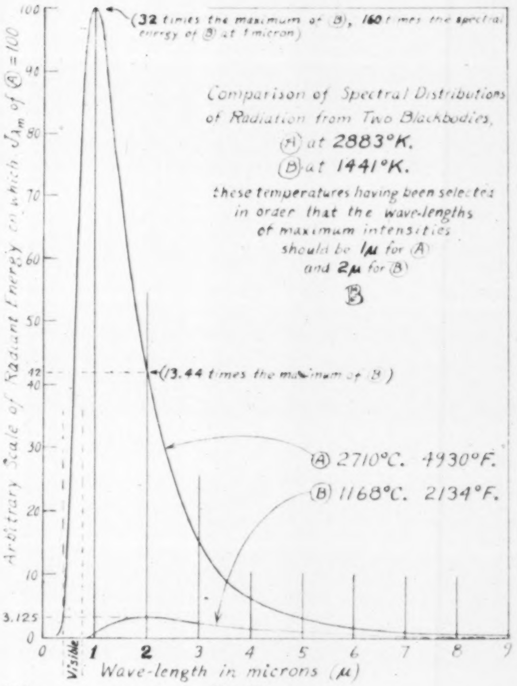


Fig. 21
Linear wave-length scale

tremely difficult to realize in practice. The simplicity of the radiation laws and of the *basic* instrumental principles are defeated by the limitations of geometry and of the materials available for making instruments to be used by persons who are not highly-trained experimental physicists. Moreover, the most serious causes of inaccuracy in radiation pyrometry are outside of the instruments. The radiant flux sample seldom exactly represents the source temperature because: (1) actual materials do not radiate as blackbodies; and (2) media intervene between the material sources and the receivers.

Sources—Effects of Materials and Surfaces.

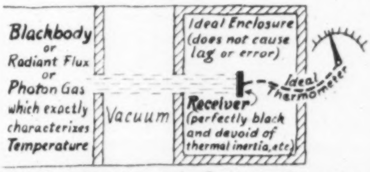
Enclosures and Cavities.—Before taking up materials and surfaces, it may be well to consider the possibility of nullifying most of their effects in actual industrial practice. Can the ideals be approximated, so that the imperfections of gross matter will not give serious trouble?

Since the most essential condition is a blackbody source, every effort should be made to approximate it. Although this ideal is unattainable when the problem is to measure the temperature of a surface in the open, it can sometimes be closely approximated when kiln or furnace temperatures are to be measured. A uniform-temperature enclosure emits radiation through a small hole as does a blackbody.

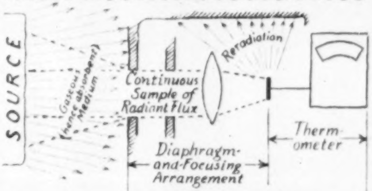
Moreover, there is an easy and generally reliable method of determining —literally at a glance—the closeness to blackbody conditions: If, when viewing a number of objects in the furnace, the outlines of these objects are invisible, the radiation will represent the temperature.

The value of this simple test depends on there being on the furnace floor two or more objects which have widely different emittances and reflectances in the open not only at room temperature but at red heats. If the objects selected for the visual test have been selected by eye, although they may have had enormously different reflectances in the open and at room temperature, they may still be unsuitable because even if their outlines merge as viewed by eye, there might not be complete equilibrium as viewed by the "eye" of a total receiver.

At dull red heats, differences between an actual and an ideal enclosure as sources are serious. The higher the temperature, however, the less serious they are, for three reasons: (1) more of the energy radiated by the source lies in the visible, so that the value of the eye as a testing instrument is enhanced; (2) the emittance properties of many actual materials go up; (3) the fourth-power relation makes smaller the temperature-measurement errors due to nonblackbody conditions. Therefore, such enclosures as ferrous-materials melting furnaces (2000 to 3000 F.) make excellent sources, provided only that the obvious geometrical requirements (Section 4) are met. The same applies of course to high-temperature measurement problems where it is possible to view the inside of an enclosure through a relatively small hole—provided that the image-size and other such factors are correct.


Blackbody or Radiant Flux or Photon Gas which exactly characterizes Temperature
Vacuum
Ideal Enclosure (does not cause lag or error)
Receiver (perfectly black and devoid of thermal inertia, etc.)
Ideal Thermometer

The Ideal Conditions *for* Radiation Pyrometry


SOURCE
Gaseous (hence absorbent) Medium
Continuous Sample of Radiant Flux
Reradiation
Diaphragm-and-Focusing Arrangement
Thermometer
Pyrometer

The Customary Elements *of* Radiation Pyrometry

Fig. 22

Next to eliminating the effects of imperfections of material radiators, the CLOSED-END TUBE offers a satisfactory solution of the source problem because with proper care its radiating properties remain constant. It is suitable for use not only in furnace walls but in molten metals.

When neither an enclosure nor a closed-end tube can be used as a source, it sometimes is possible to take advantage of a DEEP CAVITY in a casting or other object whose temperature is to be measured. The dimensions of the cavity must be at least as large as those of the closed-end tube specified for a particular radiation pyrometer.

Importance of Distinguishing Between a Type of Material and an Actual Specimen and Surface.—Perhaps the most inexcusable mistake in using a radiation pyrometer is to accept uncritically the table of emissivities furnished with the instrument. The resultant errors are relatively small when taking the temperatures of high-emissivity materials; relatively large when sighting low-emissivity materials.

The emiss*ivity* given in a table is that of a "standard" or "normal" material. The corresponding property of the *surface of an object* is EMITTANCE. The values of the emittances of various

copper objects, for example, differ by several hundred percent from the published value of the emissivity of bright new copper.

Without qualification, "emissivity" conveys the idea of rays shooting out at right angles from a surface. Therefore it is further necessary to distinguish between *normal* and *hemispherical* emissivities, for these two properties never have the same value for any material: only the blackbody obeys the cosine law. When the temperature-measurement problem is such that the surface must be viewed at an acute angle, it becomes necessary to apply two emittance corrections: that for the emittance of the individual surface and another correction taken from the curve of *relative* emissivity of the material for the angle in question—provided of course that the surface of the individual body be clean and smooth.

A corrugated or serrated surface is a special problem in itself: it will have almost normal emittance when viewed from a point so situated that the greater portion of each ridge is normal to the line of sight; or—putting it in a different way—its hemispherical emittance will be a meaningless value because of the pseudo-polarization. Some machined surfaces are extremely tricky.

The emittances of irregularly rough surfaces differ erratically and unpredictably from the emissivities of the material. Consider for example a honeycomb, or any other "surface" which is about 90 percent deep holes and 10 percent outer surface: the composite will have emittance properties close to unity (blackbody), even if the material has a low emissivity and if the outer surface is highly polished.

Thus, in the great majority of cases, an emittance (total or spectral; normal, hemispherical or for a specified angle) of an individual surface is *greater than the corresponding type of emissivity of the material.*

The Graybody is one whose spectral emissivities are all less than unity and all have the same value. In other words, the *form* of its spectral radiancy distribution curve (the "color") is like that of a blackbody but the radiancy of the source is less than that of a blackbody at the same temperature. Whence, ease of applying correction factors. Graybody conditions are rare in radiation (not optical) pyrometry.

Effects of Atmosphere and Other Intervening Media

The Gray Medium.—Next to the ideal intervening medium—a perfect vacuum—there is another nearly-ideal medium, which makes calibration a simple matter and does not contribute unsuspected sources of errors. The gray medium is one that reduces all spectral intensities in equal proportion. There are no perfectly gray media in Nature. The gray effect is realized by rotating-sector ("flicker") devices or by diaphragms or by opaque-mesh screens, but these are not media. Every total-radiation pyrometer is to some extent a selective-radiation pyrometer in actual use.

The sharp cutoffs in the ultraviolet and in the infrared of the radiation from the sun and stars being known to every high-school graduate, the impression has grown that terrestrial atmosphere errors greatly diminish the usefulness of radiation pyrometers. This is not the case. *Furnace* atmospheres are the offenders—not clean air at the usual source-to-pyrometer distances of several feet or yards. Even in the medium-humidity climates of American industrial centers, the usefulness of the radiation pyrometer, as a type of temperature-measuring instrument, is not greatly diminished thereby. Allowance can be made for the cut-off of infrared by CO, CO_2 and water vapor, and for the gray-medium effect of solid particles, under the following conditions:

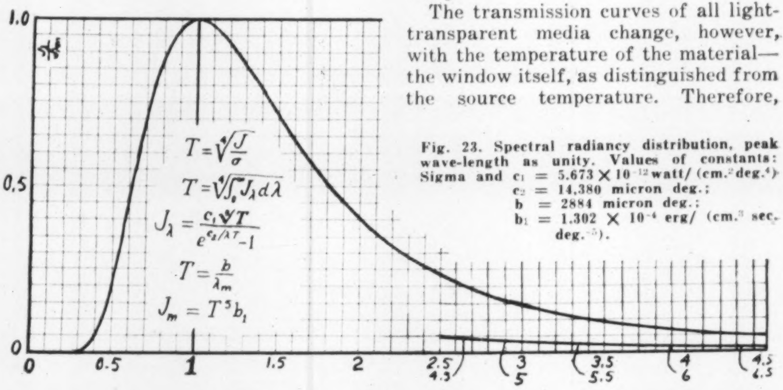


Fig. 23. Spectral radiancy distribution, peak wave-length as unity. Values of constants: Sigma and c_1 = 5.673 × 10^{-12} watt/ (cm.^{2} deg.^{4})
c_2 = 14,380 micron deg.;
b = 2884 micron deg.;
b_1 = 1.302 × 10^{-4} erg/ (cm.^{3} sec. deg.$^{-5}$).

(1) The *proportions* of absorbing gases, vapors, dust, etc., in the atmosphere between source and receiver must all be *constant.*

(2) The *distance* between source and receiver must likewise be *constant.*

These two conditions are interdependent. If any one of the various proportions of absorbing gases, smoke and moisture in the atmosphere is exceptionally high, this particular proportion will probably be variable and the total atmospheric absorption will not be constant; errors will be introduced.

Humidity being generally uncontrollable, it sets a limit to the distance even when the atmosphere is otherwise standard and clean. Where the humidity error tolerance is 1 percent of pyrometer scale range, for example, the extreme limit will be (theoretically) about a mile in a dry climate and under ten feet in a moist climate.

This distance limit will in any case be a complicated exponentional function by reason of the Bouguer-Lambert law of absorption, plus modifications for "haze" which seems to require putting both distance and particle-concentration in the exponent, as in Beer's law.

Excessive dust causes errors but, being visible, it should simply prevent taking readings when present.

Flames.—When combustion goes on in a furnace or kiln, its atmosphere absorbs *more* of the radiant flux from objects sighted through it.

Lenses and windows (parts of the pyrometer).—Here we consider the effects of interposing such media between the source and the receiver proper. Most media transparent to light cut off in the ultraviolet—which matters little. They cut off a large portion of the infrared—which greatly alters the calibration curve. Even a thin mica window to keep out dust will affect the *entire* curve.

Different glasses have greatly different transmission curves. These remain constant throughout the life of the window unless discoloration flaws develop.

The transmission curves of all light-transparent media change, however, with the temperature of the material—the window itself, as distinguished from the source temperature. Therefore, windows should be kept at fairly constant temperatures: the variations should not exceed 100 F. degrees.

To summarize: The effect of a fairly non-selective medium, or of a number of media whose joint effect is fairly non-selective, is a "grayish" effect, reducing the area of the curve without seriously altering its form. Temperature remains the fourth-root of the area under the curve—the fourth-root of the *reduced* area. Selective absorption alters the relation in raising the power from 4 to a greater exponent. Accuracy depends on CONSTANCY.

3. TYPES OF RADIATION PYROMETERS

Radiation pyrometers may be classified into (1) portable (2) permanently installed. A portable pyrometer *in use* is subject to intervening-medium errors, also to sources of error arising from its own variable temperature. However, when this same portable instrument is correctly installed, properly sighted into a closed-end tube, and otherwise subjected to uniform constant conditions, it seems to become a different type of instrument. The writer proposed in 1939 the following prime division:

1. Hand
2. Autometric and autographic

—which means that a pyrometer consisting as usual of a receiving tube and an electrical instrument will be a "hand" pyrometer while being used as such, on different sources; and it will become an autometric or autographic pyrometer when properly installed. Conversely, an autometric or autographic pyrometer will be converted into a hand pyrometer when its tube is removed from the bracket or other such device.

The important prefix "auto-" signifies that the measurement is truly automatic, for the source is a part of the inner area of the closed end of *one* refractory tube; and the intervening medium is presumably a negligible factor. Therefore the scale readings are trustworthy: *the instrument does not require a set of emittance correction tables or charts.*

By implication, the uncorrected readings of a hand pyrometer are not trustworthy. This is no fault of the instrument.

The endings "-metric" and "-graphic" refer to indicators and recorders, respectively.

The closed-end refractory tube is an essential part of the autometric and autographic instruments. A recording radiation pyrometer, whose radiation-receiving cell is installed at the side of a conveyor where slabs or billets pass from one mill stand to another, may be called a "graphic" device, but not *auto*-graphic, unless the emittance properties of the surfaces, and the transmission properties of the intervening unclean *atmosphere*, are *known to be constant.*

Another classification is into—

1. Self-contained pyrometers
2. Separate-instrument pyrometers

—which cuts across the dividing lines of various other classifications. A self-contained pyrometer is an automatic pyrometer when attached to a bracket and properly sighted into a closed-end tube for which it has been calibrated. A separate-instrument pyrometer outfit may be provided with a shoulder strap and otherwise be portable. When not used with its closed-end tube it is a *hand* pyrometer.

Another important classification has to do with the type of radiant flux sampling system. This consists of the diaphragm, the focusing system, and the receiver proper. There are no "types" based on forms of diaphragms; but there are two classifications based on the entire radiation-collecting and -focusing systems, as follows:

I. 1. Fixed-focus	II. 1. Cone
2. Variable-focus	2. Mirror
	3. Lens

In practice the cone type is of the fixed-focus type; therefore there are not six composite types, but only five.

Note that most of the radiation falling upon the receiver proper in the cone and mirror types is *reflected.* There is no such thing as a perfect reflector of all wave-lengths.

The *receiver proper* (the "sensitive element") may be of any form. A morphological classification of receivers is difficult because their form is governed by that of the primary element of the thermometric system. Thus the simplest combination of a receiver and thermometer is a tiny bimetallic spiral.

There is an obvious classification of the thermoelectric and bolometric receiver types into "open" and "glass-enclosed" or "bulb." These latter, in turn, may be divided into "vacuum" and "gas-filled," also into "glass" and "fused silica." By the same token the "open" types can be divided into those which are completely open to source radiation without intervening lenses or windows, and those which are embodied in receiving tubes of the lens type (or of the mirror type in which there is a window). Thus an "open" disk in a lens type tube (or in a windowed mirror type tube) will have certain characteristics in common with a disk in a gas-filled bulb at the focus of a windowless mirror type pyrometer tube. One of these common characteristics—convection as a cooling factor—will not be shared by the vacuum receiver, which is cooled by reradiation and conduction. But other details of the design and construction of the entire units determine the speed of response and other time characteristics. For example the glass bulb may be enclosed in a closely-fitting metal case (with a hole for the passage of the flux to the disk) in order to make the reradiation from the disk less dependent upon the temperature of the outer tube of the assembly. Thus the sub-types and varieties multiply themselves as these factors are taken into consideration. On the whole, it does not seem justifiable to speak of the "advantages" and "disadvantages" of such interlocked and interdependent types, sub-types and varieties.

The final classification is according to the method of measuring the temperature of the receiver proper. A list of possible methods would coincide with most of the items in some of the tables given in Part 1 of Chapter I. In practice, the great majority of systems are thermoelectric, but some utilize bolometer receivers in the form of blackened metallic ribbons or films serving as resistance-thermometry primary elements of extremely high sensitivity.

Pneumatic-thermometry methods, developed during the Second World War and not yet fully industrialized, deserve mention because they make possible rapidly-responsive and extremely sensitive receivers. The utilized effect is the change in pressure or volume of a small sample of gas resulting immediately from the change in temperature of a blackened membrane. Successful military applications suggest that pyrometric applications will be useful.

4. Notes on Applications and Calibrations

The geometry of receiving tubes is such that the readings should be independent of the distance from the source.

When a constant-temperature source is available, the effects of varying the distance of the receiver can be readily determined. Measurements at distances greater than the manufacturer's recommendation can be made and gradually diminished in steps until the instrument is as close as conditions permit. The readings can then be taken in the reverse order, and a plot of the results will show the best distance. One may be sure that the safe distance is not being exceeded as long as increasing the distance does not decrease the reading.

Another informative series of tests applies only to the collecting-lens receivers. The maximum permissible working distance will be found to vary with the furnace temperature. The reason is that the higher the temperature, the wider the spectrum and consequently the wider the image, because the lens is not "achromatic" for total radiation.

A closed-end refractory tube giving nearly-blackbody conditions is recommended for permanent installations. An essential requirement is constancy of atmosphere in the tube. Some refractory materials are porous to CO and CO_2. If air purging is impracticable, efforts should be made to keep the absorption of radiant flux by gases and fumes constant.

A radiation pyrometer can be calibrated against a nearly perfect blackbody such as a porcelain tube with its closed end heated by an electric coil to keep the atmosphere pure. The temperature of this blackbody should be accurately measured by means of a good standard pyrometer.

The bad reputation of radiation pyrometers with regard to response speed is largely due to the structure of the receiving tubes. The receiver proper may be thinner than tissue paper and smaller than a dime. Its INTRINSIC characteristic time (see Chapter XII) may be somewhat less than a millisecond. But the temperature T1 which it first attains after a change in sighted-source temperature is not the temperature T2 which, under calibration conditions, represents the source temperature. T2 is the EQUILIBRIUM temperature to which the receiver finally comes after the much slower heating (or cooling) of the nearby surfaces of the relatively large and heavy surrounding structure. In some designs, after a sudden change in source temperature, the electrical-instrument pointer jumps to a new value, drifts back to a "first equilibrium," then slowly oscillates, only coming to rest at the "final equilibrium" after one minute or longer.

As with most other industrial instruments, the important thing in the large majority of applications is not so much to measure a "true" temperature as to be able to reproduce a process temperature day after day. The radiation receivers and their associated electrical instruments, as well as the self-contained industrial radiation pyrometers, although not entirely fool-proof, give years of satisfactory service if calibrated as frequently as circumstances require.

Above all, keep the collecting lenses and mirrors clean and do not subject the receiver case (of most designs) to temperature fluctuations.

PART 4—VISUAL OPTICAL PYROMETRY

Definition.—Visual optical pyrometry is the measurement of high temperatures by eye.

Implications: (1) "Measurement" not only excludes the old art depending on the UNAIDED eye of the expert, but implies the use of instruments yielding QUANTITATIVE results on scales calibrated against the International Temperature Scale. (2) "High temperatures" implies sources whose radiant flux contains enough luminous flux for the Wien and other laws to be utilized. (3) "By eye" excludes the autometric instruments: these are dealt with in Part 5.

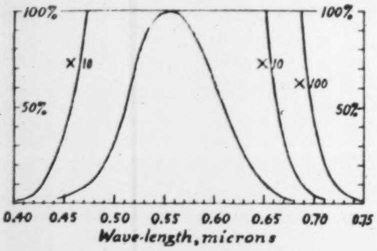


Fig. 24. The normal visibility curve

Utilized Laws.—The most important thermal-radiation laws have been dealt with in Section 1 of Part 3 and need not be discussed again in detail. Briefly these are: (1) the fourth-power relation between temperature and radiant flux; (2) the fifth-power maximum-intensity law; (3) the spectral radiancy distribution or displacement law. *Optical* pyrometry—or selective-radiation pyrometry, or spectral-radiation pyrometry—consists mainly in the application of the second and third laws. *Autometric* optical pyrometry is not limited as to spectral region* but *visual* optical pyrometry is limited by the spectral sensitivity curves of human eyes. Since no two individuals have exactly the same vision, the best visual optical pyrometric methods are those which eliminate—or minimize—individual differences.

The fifth-power law is the basis of various classes of instruments which measure the temperature of a source by its BRIGHTNESS; the displacement law is utilized in various classes of COLOR and COLOR-RATIO instruments.

Extreme Sensitivity.—In all classes of instruments the function of the observer may be likened to that of a null-point detector: his eye is only required to match two brightnesses, to judge an extinction point, etc. The spread of null-point determinations by different observers—or by one careless observer—which would mean serious errors in the use of linear-scale-law instruments, is of less consequence because of the tremendously steep slope of the instrument scale laws made possible by either the brightness-change or the color-change effects selected by the instrument designers in utilizing the radiation laws. (By the same token, large errors may result from small maladjustments of instrumental internal standards, small aging effects, and other instrument features.)

The steepness of these slopes does not require an elaborate explanation. Even the unaided eye can detect a remarkably small increase or decrease of the temperature of the coil of an electric heater in a darkened room—particularly the difference between "first visible red" and "dull red." Keen-eyed boys or girls, after about ten minutes for dark-adaptation, can tell the difference between 970 F. and 975 F. Anyone with normal vision, after an hour or so in the dark, can detect the 30-degree difference between 945 F. and 975 F. under such conditions, because at 945 F. the coil does not glow visibly and at 975 F. its glow can be seen by the dark-adapted normal eye. (In modern well-illuminated plants the first visible red for most individuals is somewhat above 1030 F.) The relation between brightness change and temperature change is far more than the fifth power and may be said to be infinitely great in the threshold region.

Next, if the knob of the electric heater is turned until the coil glows bright red (about 1300 F.), and then turned up and down slightly, most observers will be able to detect changes corresponding to 100 F.° (some observers, 50 F.° or less). But now these changes are of two kinds:

(1) The brightness of the heating coil varies enormously with temperature—as the twentieth to twenty-second power of the absolute temperature.

(2) The color of the coil changes—from what an average observer might call deep red at 1200 F. to what he might call bright red at 1400 F. The displacement-law shift, from 1200 F. to 1400 F., increases the orange content of the radiation by a relatively small amount in terms of spectral radiant flux and by a twenty to thirty times greater amount in terms of spectral luminous flux because of the eye's sensitivity curve. Thus the normal eye does perceive a color change. Even this visibly-observable color change, however, is "great" or "little" depending partly on the observer's judgment, partly on his special training, and partly on the room's illumination. As compared to the brightness change, this color change ALONE is too small for the UNAIDED eye to MEASURE temperatures to better than 200 or 250 F., as verified by simple tests in bright sunlight or by tests in which the brightnesses of sources at different temperatures are equalized.

Hence the wide usefulness of the various types of MONOCHROMATIC visual optical pyrometers which allow only red light (usual effective wave-length, 0.65 micron) to enter the observer's eye and thereby increase the accuracy of temperature measurement in two ways:

First, this eliminates the color-change effect and thereby eliminates the factor of individual differences in color judgment or color sensation. Sufferers from the various types of color-blindness can obtain the same results with monochromatic visual optical pyrometers as do users whose vision conforms closely to the International Visibility Curve.

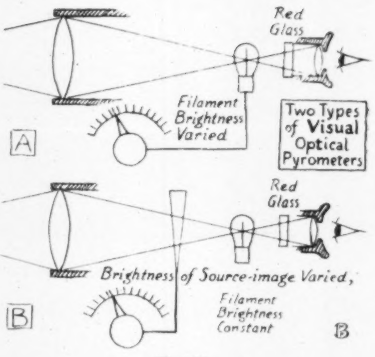

Red Glass
Filament Brightness Varied
A
Two Types of Visual Optical Pyrometers
Red Glass
Brightness of Source-image Varied,
Filament Brightness Constant
B
B

Fig. 25

Second: The only Utilized Effect is the variation of a monochromatic intensity, so that the nature of the measuring-system receiver does not matter. To the eye the only variation is a brightness variation; to the blackened thermopile or bolometer of an autometric instrument it is a heating-effect variation. Thus the spectral LUMINOUS intensity and the spectral RADIANT intensity of the source whose temperature is measured are the same magnitude to the measuring system, whether this system be humanly-operated or automatically-operated.

Monochromatic Means incorporated in visual optical pyrometers may be classified into (1) filters and (2) spectroscopic devices. Filters are used in portable instruments; they range from single sheets of red glass or other materials to compound filters consisting of two or more sheets transmitting only a narrow band of wave-lengths. Spectroscopic arrangements give the highest attainable spectral purity; their weight and bulk limit their use to laboratory pyrometers.

Comparison Sources.—Great as is its variation with temperature, the brightness is not measured directly by the observer's eye. In using a monochromatic instrument the observer sees in his field of view two images (or one or two divided images—these are design details) and his easy task is to turn a knob to adjust one of the two brightnesses until it matches the other—until the two or more visible objects disappear and he sees only a round area of uniform brightness.* The *Reference Standard* of the comparison brightness, or the *Comparison Source* as it is also called, is the most important component of the pyrometer. In some pyrometers this source is off to one side and is reflected into the field of view by a prism, a mirror, or both. In others it is an incandescent filament or ribbon which cuts across the field of view. The external or internal source is usually made of tungsten and conforms to the rigid specifications elaborately developed by the lamp industries' laboratories and by the National Bureau of Standards.

In some pyrometer-calibration laboratories the *Primary* standard source is a high-temperature black-body (such as the one described in *Bu. of Stds. Research Paper* 325) which utilizes molten platinum. Most industrial pyrometer-

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*Except in *each* instrument by the spectral sensitivity curve of its receiver; but today the number of available materials and methods permits measuring flux intensity at all wave-lengths, even far beyond the limits of the spectra of interest in pyrometry.

*This ideal is difficult of attainment. The classic discussion of this subject is that by Fairchild and Hoover (*J.O.S.A.*, vol. 13, p. 635).

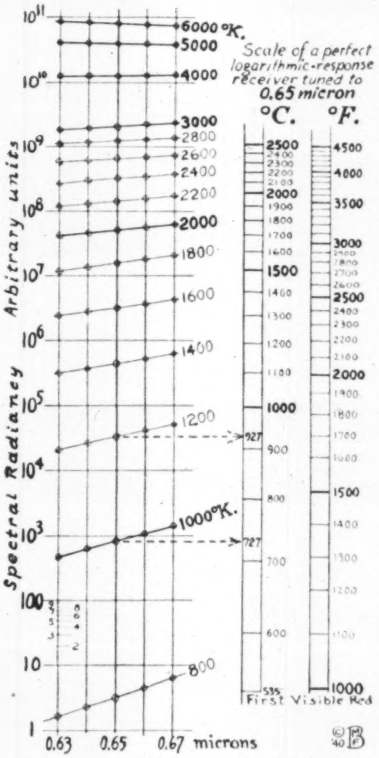

Fig. 26. The foundation of monochromatic optical pyrometry.

calibration departments, however, use the Bureau's secondary standard, which is a tungsten-ribbon lamp designed especially for calibrating optical pyrometers.

Brightness-matching Systems incorporated in monochromatic instruments may be roughly divided into (1) photometric types and (2) disappearing-filament types, although some disappearing filament types utilize old photometric methods in modern embodiments for obtaining the match. Before the nineteen-thirties the consensus favored photometric methods because the assemblages of electrical components such as batteries, rheostats, ammeters, etc., (of small-enough bulk and weight) usually had a large TOTAL error—which commonly became intolerably large after months of service. The situation gradually altered with the appearance of precision miniature components and even more so with the appearance of new circuits—such as (a) instruments incorporating both the usual "working lamp" and a periodically-used "master lamp"; (b) instruments employing a new POTENTIOMETER circuit whereby the emf. of a STANDARD CELL becomes the periodically-used reference standard; (c) numerous other electrical developments permitting portable industrial pyrometers to utilize electrical features previously found only in laboratories. Without these recent advances in electrical instrumentation, the extraordinarily high accuracy of the monochromatic METHOD would not be attainable with non-photometric instruments.

Non-blackbody Objects.—Minimization of instrumental errors in modern monochromatic visual optical pyrometry has made it all the more necessary to call attention to errors arising from the non-blackbody nature of the various objects sighted in practice.

An extreme example: look through your pyrometer at a well-illuminated sheet of paper; turn the knob to get a match; read the TEMPERATURE scale.

Most readers already know, from taking color movies or stills, that this reading (obtained with an industrial pyrometer) will be fairly close to the *color temperature* of the paper and that the special "color temperature meters" are designed to give the true color temperature. The temperature scales of visual optical pyrometers are calibrated on the basis that the object whose temperature is to be measured is a blackbody. This is realized (or closely approximated) ONLY when the object is sighted through a small opening in a furnace wall and when other conditions discussed in Part 3 are met. As in total-radiation pyrometry, the commonest—and least-suspected—errors stem from the difference between the properties of the SURFACES sighted and those of the MATERIALS listed in tables of emissivities.

In monochromatic visual optical pyrometry, these errors are less serious than in total-radiation pyrometry. Reason: scale-law slopes are much more than the fourth power of the absolute temperature. It must be borne in mind, however, that this power varies inversely with temperature. At red-heat temperatures (close to the threshold) the relation is in the twenties; at 4437 K. (4164 C. or 7283 F.) it is exactly the fifth power, because at that temperature the maximum-intensity wave-length of a blackbody coincides with the effective wave-length of the red filters. Consequently, the emittance errors increase with temperature. Rough estimates of emittances may be permissible when measuring temperatures below about 1600 F.; but—as shown by Fig. 27—exact knowledge of emittances is necessary above 2500 F. For example, if the emittance of a surface is 20 percent, the errors will be (roughly):

True temp., F.:	1500	2500	4000
Error, about:	200	400	900

TABLE III—CLASSIFICATION OF VISUAL OPTICAL PYROMETERS

Division	*Class*	*Type*
Brightness	Photometer 1. Equality field 2. Contrast field 3. Flicker Etc. photometrically	Variable distance Variable diaphragm Absorbing wedge Rotating sector Rotating polarizer
	Disappearing-filament 1. Ammeter 2. Potentiometer Etc. electrically	Variable current Variable diaphragm Absorbing wedge Rotating sector
Brightness Color	Extinction of total luminous flux	"Gray" wedge
Color	Extinction of most-visible color	"Green" wedge
	Color ratio	Two colored wedges do. + absorbing wedge

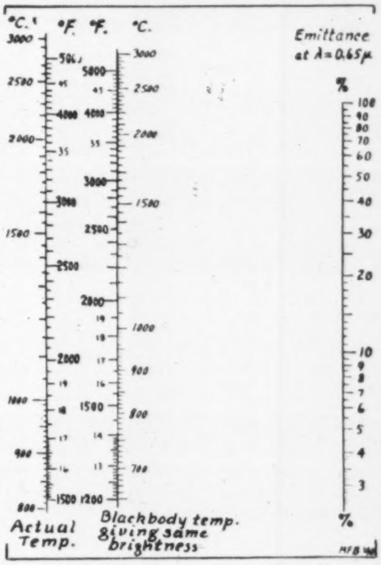

Fig. 27. Emittance corrections.

Two other points should also be borne in mind: (1) spectral emittances at 0.65 micron may differ from published values of total emissivities; and (2) emittances of most objects vary with temperature.

Errors due to variability of emittances can often be minimized by sighting certain kinds of spots or regions on the surfaces of molten materials or solid objects, and avoiding others, as taught by long-experienced pyrometrists in some industries.

Other Visual Optical Pyrometric Methods

Monochromatic methods stand out in relative importance; the others are so numerous that space limitations prevent discussing them in detail.

Color Pyrometers (several classes and many types) ordinarily utilize the RATIOS of intensities of any two frequencies such as blue and red, green and red, etc. If perfect colored glasses and other media were available, these instruments would become more popular, for their construction is generally simple and some of them are vest-pocket size. The color ratio is determined in various ways by moving the two filters (and sometimes a third "gray" filter) in relation to one another. Users must not be color-blind.

The *Extinction* class belongs both in the "brightness" category and in the "color" category.

One popular type comprises a glass or dyed gelatin screen which transmits more blue and red than the intervening colors of the visible spectrum. This screen is denser at one end than at the other. The observer slides it back and forth until he finds the spot (or region) where he barely sees the source.

An even simpler type in the extinction-wedge class consists of a green wedge: the green is not spectrally pure, so that a red-hot source can be seen through the clearer end, a yellow-hot source through the middle, and only a dazzling-white source through the denser end.

The simplest type is a "gray" or neutral or achromatic wedge—or rather an approximation of this irrealizable ideal material.

The variable-color-ratio pyrometers and the fixed-color-ratio extinction-wedge pyrometers are sometimes claimed to have an advantage over brightness-matching pyrometers, namely that corrections for the emittances of actual surfaces are negligible in their use. This is only a theoretical advantage. There are types, however, embodying a special wedge which is adjusted for emittance, thereby making the instruments direct-reading in true temperature.

Line-reversal Methods.—All of the previously-mentioned methods are subject to errors if the source emits a line spectrum instead of a continuous spectrum, or if it emits a combination, i.e., a spectrum with strong lines near the effective wave-length of the filters. This ordinarily-troublesome effect is the very one which Féry first utilized for measuring flame temperatures. A standard tungsten-ribbon lamp is viewed through the flame and (if the flame itself does not contain the desired line-emitting elements) table salt is sprinkled in the flame; and lamp and flame are viewed through a prism at such an angle that the well-known yellow sodium line is in the middle of the observed part of the spectrum. When the lamp temperature is higher than the flame temperature, the sodium line appears black (as do also the fainter lines of elements in the flame); conversely these lines appear bright; when the lamp temperature has been adjusted to equal the flame temperature, all lines disappear and the partial spectrum seen by the observer is continuous. The sodium line being an extremely strong one—whether as a black line or a bright line—it permits easy matching. Moreover, the non-blackbody correction factor for the particular standard lamp is exactly known.

PART 5—AUTOMETRIC OPTICAL PYROMETRY

(Selective Physical Receivers)

The distinction between visual and autometric optical pyrometers existed long before the advent of electric eyes but no one could then foresee the industrial usefulness of optical-but-not-visual pyrometers. Therefore, the term radiation pyrometer denoted an instrument responding unselectively to the total flux, that is to say, to the *radiant* flux; and the term optical pyrometer referred to an instrument aiding the human eye to measure the temperature of a source by the character of its *luminous* flux—which requires selective reception.

Those highly-selective receivers, the spectroscopes, had appeared several decades before radiation or optical pyrometers. In 1886 Langley had invented the bolometer and combined it with a spectrometer. His spectroradiometer might be called the prototype of autometric optical pyrometers. A modern spectroradiometer, with its deviation screw clamped to one wave-length, and with a direct-deflection instrument instead of a laboratory galvanometer, can be calibrated in degrees of continuous-spectrum source temperature by the application of the Wien laws. Its sensitive element or RECEIVER-PROPER may be a blackened thermopile or bolometer which utilizes the heating effect of radiant energy as does an ordinary radiation pyrometer, but the pyrometer cannot be calibrated by the fourth-power law, for it is not a total-radiation pyrometer but an OPTICAL pyrometer, with the narrow spectral selectivity that characterizes optical pyrometry. As to the word AUTOMETRIC, it connotes a continuously-measuring PHYSICAL receiver instead of the eye (which is not only a psychophysical receiver but can only measure intermittently).

In practice, the heating effect of an extremely narrow band of wave-lengths is so weak that the thermopile or bolometer output must be greatly amplified and extreme precautions taken. The cost of the requisite apparatus is not objectionable in precision spectrographs and automatic curve-drawing spectrophotometers, but it makes such instruments the highest-price pyrometers. Hence the scarcity of spectroradiometer pyrometers.

Photoelectric Receivers are the devices which have made possible the new industrial field of autometric optical pyrometry. Phototubes and photocells comprise a rich variety of commercially-available models.

In common with autometric total-radiation pyrometers, autometric optical pyrometers make possible remote automatic control, continuous recording and other modern developments; and likewise require various precautions such as water-cooled receiver housings.

Units with closely-similar spectral (and other) responses being commercially available, the replacement problem is minimized by interchangeability. Units are available in various shapes and sizes. Their "fatigue" and "aging" limitations for precision measurements utilizing linear effects are almost negligible in pyrometric use because of the higher powers. The milliampere output of a typical unit without any monochromatic filter will vary as the twelfth power of the absolute temperature in the 2000-to-3000 F. region, because its sensitivity curve is both sharp and with its peak in the yellow-green.

Most narrow-curve photoelectric receivers (phototubes as well as photocells) yield extremely steep scale laws without filters, by reason of their own selectivity.

Low-temperature Optical Pyrometry

From the simple inverse relation of temperature to peak-intensity maximum wave-length, it is obvious that an optical pyrometer using a 6.5-micron effective wave-length (instead of the 0.65-micron wave-length of monochromatic visual instruments) would have a scale-law slope as steep to changes in room temperature as the scale law of ordinary visual pyrometers is to high temperatures. Theoretically, the heating effect of a narrow band in the 6-micron region could be used by an instrument with an ultrasensitive thermopile or bolometer receiver. In practice, this is unnecessary because temperatures below red heat are successfully measured by the total-radiation receivers dealt with in Part 3. As for using a phototube or photocell, no practically-usable element or compound has a sufficiently low work function for the feeble far-infrared photons to produce the photoelectric effect. Several types of phototubes and photocells do respond in the NEAR infrared and have lowered the usual limit of 1000 F. One new type deserves individual mention:

The *Lead Sulphide Photocell* is a photoconductive type developed during the Second World War by the (British) Admiralty Laboratories. It responds to wave-lengths as long as 3.6 microns and the shape of its curve is such that this photocell may be considered a monochromatic receiver of 1.98-micron effective wave-length. Therefore it has been used successfully for measuring blackbody temperatures as low as 212 F. The limit depends as usual on the emittance of the surface whose temperature is measured. For an emittance of 0.3 the lowest measurable temperature is about 570 F. (Below these limits, the required amplification is troublesomely high.) The characteristic time of the lead sulphide cell being only a few microseconds, it has been used to record millisecond-period temperature variations by feeding its output to an oscillograph. The cell itself being commercially available, it is safe to predict that complete pyrometers employing it as the receiver will soon be on the market.

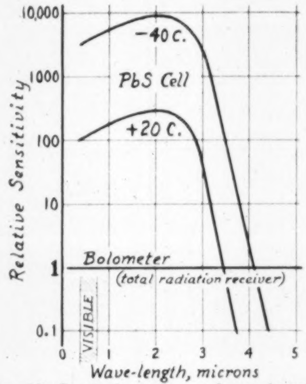

Fig. 28. Spectral response of an American-made lead sulphide cell at two temperatures (of the cell itself). Refrigerated housings are used for extreme sensitivity.

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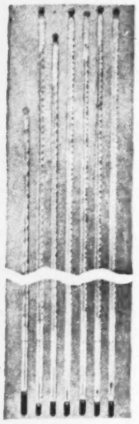

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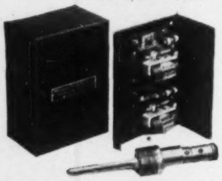

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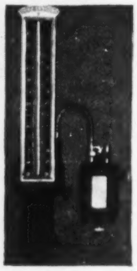

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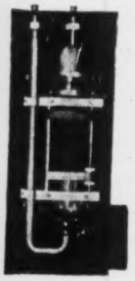

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CHAPTER III

PRESSURE AND VACUUM

By M. F. BEHAR

PART 1—GENERAL INSTRUCTIONS, TABLES, ETC.

1. Introductory Notes

PRESSURE is as universal a processing and working condition as temperature. Even where it is ordinarily ignored, as on an assembly line, it exists in the form of atmospheric pressure. The effects of pressure on boiling and condensing points, reactions, process efficiencies, costs, etc., are of the utmost importance.

Recent years have witnessed an amazing extension of the industrial pressure range in both directions, so that ten thousand pounds per square inch and a ten-millionth of a pound per square inch (expressed otherwise, of course) are commonplace working pressures, indicated, recorded, and frequently controlled by every-day instruments and apparatus. This is mentioned in order to call attention to the interesting fact that the range of pressures measurable by instruments is 10^{15}. In other words, instruments have been developed to measure pressures a thousand million million times greater than pressures which other instruments have been designed to measure.

2. Definitions, etc.

Pressure is exactly defined as force applied to, or distributed over, a surface; and is measured as force per unit area. Although other technical meanings are sanctioned by general dictionaries, engineering terminology has purposely reserved other specific terms such as "stress," "load," "weight," etc., in order to avoid confusion.

By a Pressure Instrument is usually meant one for the measurement of the pressure exerted by a fluid, a qualifying word or phrase being added for the exceptions. Example, a "soil pressure" indicator. Most pressure instruments measure a difference between two pressures, one usually being that of the atmosphere.

Absolute Pressure is actual total pressure, acting on a surface. Whatever unit is used, the zero point is perfect vacuum. This term is used of necessity in engineering work to denote that the atmospheric pressure need not be added, or has been added. Addition is algebraic: for "a vacuum of two inches of mercury," when the corrected barometric reading is 29.9 inches, the value of the absolute pressure is 27.9 inches.

Absolute Pressure Gages are those which are not affected by barometric pressure in their indications of pressures to which applied. The simplest example is the closed-end U-tube. A barometer is an absolute pressure gage applied to the atmosphere and therefore measuring only the atmospheric pressure.

Gage Pressure is that which is indicated by open-end liquid-column manometers and by Bourdon and other hollow-spring and diaphragm gages. In such instruments the measured pressure acts on one side, and the atmosphere on the other, of the pressure-responsive element. When such gages are not connected, the same pressure acts on both sides and they read zero: A gage reading zero in the open will still read zero if placed inside an evacuated vessel. Such gages therefore indicate the difference between the absolute pressure to which they are connected and the atmospheric pressure around them.

These things are familiar; what is sometimes overlooked is this: Should "two pounds gage" be maintained automatically in a piece of equipment while the barometric pressure is 14 psi, the absolute or actual processing pressure will be 16 psi. Should the barometric pressure rise or fall, the processing pressure will rise or fall correspondingly because the pressure-responsive element of the usual automatic device is subjected internally to the controlled pressure and externally to the atmospheric pressure. Thus, except for rough work or in the case of pressures so high that barometric fluctuations are negligible, the corrected barometer reading must be added whenever the absolute pressure is the condition of importance. In many closed systems, however, the gage pressure is itself the important factor regardless of the barometric pressure. Thus in the case of gas to be applied at a pressure of 4 oz. per sq. in., regulators are of the "gage" type and not of the "absolute" type, because 4-oz. gage pressure is specified.

The unqualified designation Pressure Gage has thus come to refer to instruments which measure gage pressure. Some writers, however, make it a point to prefix "ordinary" or "common."

The essential point is to be specific not so much when referring to instruments as when referring to pressures. Thus "15-lb. pressure" is ambiguous—not because the area is not stated (in English-speaking countries the square inch is understood) but because, unless the context is explanatory, it may mean 15 psig. or 15 psia., the former having a value more than twice that of the latter.

Static Pressure is the force per unit area exerted on a wall by adjacent fluid which is at rest or which is flowing parallel to the conduit wall, as at A in Fig. 1. Static pressure also exists in the midst of a body of fluid at a distance from a wall. For fluid at rest, or flowing in a conduit with parallel sides of sufficient length to insure parallel flow, static pressure is the same throughout each horizontal surface in the midst of the fluid as well as at any "static hole" (see Section 8) in the wall at this surface. Static pressure is also called Line Pressure in some branches of technical work.

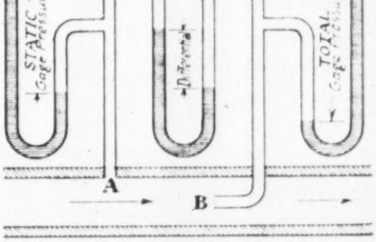

Atmospheric pressure acts equally on the two open-end manometers
STATIC Gage Pressure
Differential
TOTAL Gage Pressure
A
B

Fig. 1.

Total Pressure or Kinetic Pressure is the sum of the static and impact pressures, as at B in Fig. 1. It is greater than static pressure by an amount equivalent to the energy represented by the velocity of flow.

It is exactly defined by the statement that frictionless free expansion or isentropic expansion from fluid at rest with a pressure equal to the total pressure, into a region with pressure equal to the static pressure, will produce the existing velocity.

Impact Pressure or Velocity Pressure or Velocity Head is that due to the speed of flow. To remove all doubt from this concept, it is only necessary to think of the familiar manifestation in a shallow stream where some of the flowing water, on meeting a rock, "rises above its own level." If, instead of a rock, a tube bent at right angle be held with its horizontal leg submerged and facing up-stream, the surface of the water in the tube's vertical leg will stand higher than that of the surrounding water. Obviously a pressure must exist to cause this difference of elevation. A useful memory-aid is that this velocity head, expressed in feet, is independent of the density of the fluid. Therefore, for an incompressible fluid, or for gas or steam flowing at low velocities, the Impact Pressure, expressed as the height of a column of fluid, in feet, is numerically equal to the velocity head, $V^2/2g$. The impact pressure in Fig. 1 is the velocity head.

Static and total pressures, as usually read, are gage pressures. However, the values used more often in engineering work—particularly when computation is involved—are Absolute Static Pressures or Absolute Total Pressures, obtained by adding algebraically the barometric pressure and the gage pressure readings.

Head is defined as the height of a column or body of fluid above a given point considered as causing, counteracting or measuring pressure. So useful and convenient is the directness of this familiar term that systems of pressure units in terms of liquid head are employed in many lines of work, in preference to systems resting on the exact basis of force per area.

A Head Meter, however, is not a head gage, but a fluid meter consisting of (1) a primary element through which the stream of fluid produces a difference of pressure, and (2) an instrument which, responding to this differential head, indicates or records the rate of flow, or registers by integration the quantity of fluid. Another instrument, or a suitable second measuring element in the meter, measures the static pressure. Fig. 1 shows the pressure measurements involved.

Differential. Specifically, in fluid meter work, the differential head produced through a primary device installed for the purpose of flow measurement. Expressed in terms of head of the fluid itself, this differential depends only on velocity; expressed in head of water or mercury, the differential depends also on the density of the measured **fluid.**

Differential Gages. From the above it is evident that the simplest U-tube may serve to measure fluid flow if it is provided with a square-root scale instead of the customary even linear divisions, and if it is connected to the two different sides of a differential producer. Some glass U-tubes with fittings and accessories, not including differential producers, are called "flowmeters." But the distinction may be pointed out that whereas the measuring instruments of all head meters are differential pressure gages, a differential pressure gage, by itself, is not a flowmeter.

Hydrostatic Pressure is that due to head of liquid. Its value P at a distance h below the surface of a fluid of density d is hdg, g being the gravitational constant and the same system of units being used.

Pressure Base and Base Pressure. Since the actual quantity of any gas supplied or utilized varies not only with its volume but with its absolute pressure and inversely as its absolute temperature, a Pressure Base (usually expressed in oz. per sq. in.) must be specified. Calculations are made by adding the pressure base to the atmospheric pressure, the value of which must also be specified.

Critical Pressure is that pressure under which a substance may exist as a gas in equilibrium with the liquid at the Critical Temperature, which is that temperature above which a gas cannot be liquefied by pressure alone.

"Solid" Pressures. In some cases as with cutting tools, it is not force per area but total pressure, or load, which is understood and measured. In other cases it is more exactly the Stress, or force producing or tending to produce deformation in the body measured by the force applied per unit area.

Mano-. This prefix comes from the Greek root manos, thin or rare; which explains the derivation of manometer as meaning exactly an instrument for measuring gas pressure.

Piezo.—Greek for pressure. A piezometer is a pressure measuring instrument but this designation is reserved for special gages and apparatus. A piezometer ring is a ring-shaped pressure chamber around a straight smooth pipe section and communicating therewith by a number of uniformly-spaced similar holes normal to the conduit wall. Piezometry is specifically the measurement of the compressibility of liquids. Piezoelectricity deals particularly with those crystals which alter in size and shape in electric fields and, conversely, develop electrical charges on their faces when mechanically strained, so that they can be utilized to measure rapidly-changing pressures.

Vacuum. 1. The zero point of absolute pressure scales. 2. Negative pressure, below atmospheric; as "10 inches of vacuum."

Viscosity, in its various effects on pressure and in pressure instruments, may simply be defined as resistance to change of form.

3. PRESSURE UNITS AND THEIR CONVERSION

Four systems of units are in use:

(1) Absolute units of force;
(2) Gravitational units of force;
(3) Linear units of liquid head;
(4) Atmospheres.

The first and fourth systems being seldom employed for industrial pressure measurements in America, it is usual to say that pressure is expressed either in weight units per unit area, or in liquid head.

The relation between gravitational and absolute units of force hinges entirely on the value of g, the acceleration due to gravity. Gravitational units are g times absolute units. For English units g is substituted in ft. per sec.^{2}, hence one pound weight equals, roughly, 32 poundals. For metric units, substituting the value of g in cm. per sec.^{2}, one gram weight equals, roughly, 980 dynes.

English weight units are used in connection with English units of area; and the same for Metric. There is no necessity for hybrid pressure units such as pounds per square meter or grams per square inch. The whole situation is complicated enough as it is.

The usual English weight unit is the pound. Ounces and tons are less frequently used, the former in the gas industry on account of its convenience. The usual English unit of area is the square inch, but the square foot is sometimes used in engineering. Already we have six English pressure units; but the pound per square inch is used more frequently than all other five added together.

Both the gram and the kilogram are commonly used as Metric weight units, the centigram and decigram almost never; both the square centimeter and the square meter as area units, especially the former—the square millimeter seldom and square decimeter almost never. The number of different pressure units matters less, conversion being simply a matter of shifting the decimal point.

The liquid head system possesses obvious advantages, but is somewhat complicated by the number of linear

TABLE I—PRESSURE UNIT CONVERSION FACTORS to 5 significant figures.

		lb./in.^{2}	oz./in.^{2}	lb./ft.^{2}	ton/in.^{2}	ton/ft.^{2}	in.H_2O	ft.H_2O	in. Hg.	A_0	dyne/cm.^{2}	g/cm.^{2}	kg./cm.^{2}	cm. H_2O	m. H_2O	mm. Hg.	μ Hg.
ENGLISH	1 Pound /sq. in. =	*1.0000*	16.000	144.00	5.0000 x10^{-4}	7.2000 x10^{-2}	27.680	2.3067	2.0360	6.8045 x10^{-2}	68947.	70.306	7.0306 x10^{-2}	70.308	0.7031	51.715	51715.
	1 Ounce /sq. in. =	0.0625	*1.0000*	9.0000	3.1250 x10^{-5}	4.5000 x10^{-3}	1.7300	0.1442	0.1272	4.2528 x10^{-3}	4309.2	4.3941	4.3941 x10^{-3}	4.3942	4.3942 x10^{-2}	3.2322	3232.2
	1 Pound /sq. ft. =	6.9445 x10^{-3}	0.11111	*1.0000*	3.4723 x10^{-6}	5.0000 x10^{-4}	0.19223	1.6019 x10^{-2}	1.4139 x10^{-2}	4.7254 x10^{-4}	478.80	0.4882	4.8824 x10^{-4}	0.4882	4.8825 x10^{-3}	0.3591	359.13
	1 Ton /sq. in. =	2000.0	32000.	2.8800 x10^{5}	*1.0000*	144.00	55361.	4613.4	4072.0	136.09	1.3789 x10^{8}	1.4061 x10^{5}	140.61	1.4062 x10^{5}	1406.2	1.0343 x10^{5}	1.0343 x10^{8}
	1 Ton /sq. ft. =	13.889	222.22	2000.0	6.9445 x10^{-3}	*1.0000*	384.45	32.038	28.278	0.9451	9.5760 x10^{5}	976.48	0.9765	976.51	9.7651	718.26	7.1826 x10^{5}
	1 Inch water 39°F. =	3.6127 x10^{-2}	0.5780	5.2022	1.8063 x10^{-5}	2.6011 x10^{-3}	*1.0000*	8.3333 x10^{-2}	7.3554 x10^{-2}	2.4582 x10^{-3}	2490.8	2.5399	2.5399 x10^{-3}	2.5400	2.5400 x10^{-2}	1.8683	1868.3
	1 Foot water 39°F. =	0.43352	6.9363	62.427	2.1676 x10^{-4}	3.1213 x10^{-2}	12.000	*1.0000*	0.8826	2.9499 x10^{-2}	29890.	30.479	3.0479 x10^{-2}	30.480	0.3048	22.419	22419.
	1 In mercury 32°F. =	0.49116	7.8586	70.727	2.4558 x10^{-4}	3.5363 x10^{-2}	13.596	1.1330	*1.0000*	3.3421 x10^{-2}	33864.	34.532	3.4532 x10^{-2}	34.532	0.3453	25.400	25400.
INT'L	1 Normal Atm'ere =	14.696	235.14	2116.2	7.3480 x10^{-3}	1.0581	406.79	33.900	29.921	*1.0000*	1.0132 x10^{6}	1033.2	1.0332	1033.3	10.333	760.00	7.6000 x10^{5}
	1 Dyne/sq. cm. 1 Microbar =	1.4504 x10^{-5}	2.3206 x10^{-4}	2.0886 x10^{-3}	7.2519 x10^{-9}	1.0443 x10^{-6}	4.0147 x10^{-4}	3.3456 x10^{-5}	2.9530 x10^{-5}	9.8692 x10^{-7}	*1.0000*	1.0197 x10^{-3}	1.0197 x10^{-6}	1.0197 x10^{-3}	1.0197 x10^{-5}	7.5006 x10^{-4}	0.7501
METRIC	1 Gram /sq. cm. =	1.4224 x10^{-2}	0.2276	2.0482	7.1117 x10^{-6}	1.0241 x10^{-3}	0.3937	3.2809 x10^{-2}	2.8959 x10^{-2}	9.6784 x10^{-4}	980.66	*1.0000*	0.0010	1.00003	1.00003 x10^{-2}	0.7356	735.56
	1 Kilogram/sq. cm. =	14.224	227.58	2048.2	7.1117 x10^{-3}	1.0241	393.71	32.809	28.959	0.9678	9.8066 x10^{5}	1000.0	*1.0000*	1000.03	10.0003	735.56	7.3556 x10^{5}
	1 Cm. water at 4°C. =	1.4223 x10^{-2}	0.2276	2.0481	7.1115 x10^{-6}	1.0240 x10^{-3}	0.3937	3.2808 x10^{-2}	2.8958 x10^{-2}	9.6781 x10^{-4}	980.64	0.99997	9.9997 x10^{-4}	*1.0000*	0.0100	0.7355	735.54
	1 Meter water 4°C. =	1.4223	22.757	204.81	7.1116 x10^{-4}	0.1024	39.370	3.2808	2.8958	9.6781 x10^{-2}	98064.	99.997	9.9997 x10^{-2}	100.00	*1.0000*	73.554	73554.
	1 Mm. Hg. at 0°C. =	1.9337 x10^{-2}	0.3094	2.7845	9.6684 x10^{-6}	1.3922 x10^{-3}	0.53525	4.4605 x10^{-2}	3.9370 x10^{-2}	1.3158 x10^{-3}	1333.2	1.3595	1.3595 x10^{-3}	1.3595	1.3595 x10^{-2}	*1.0000*	1000.0
	1 Micron Hg. 0°C. =	1.9337 x10^{-5}	3.0939 x10^{-4}	2.7845 x10^{-3}	9.6684 x10^{-9}	1.3922 x10^{-6}	5.3525 x10^{-4}	4.4605 x10^{-5}	3.9370 x10^{-5}	1.3158 x10^{-6}	1.3332	1.3595 x10^{-3}	1.3595 x10^{-6}	1.3595 x10^{-3}	1.3595 x10^{-5}	0.0010	*1.0000*

units, combined with the necessity of naming the liquid and, for accurate work, of taking into account its temperature and the value of g at the latitude and elevation.

Fortunately, although liquids other than water and mercury are employed in actual manometers, only these two are used as measures. But the custom of reducing mercury head to the ice-point clashes with the obvious impossibility of doing so for water head—water columns being considered standard, for scientific work, at the temperature of maximum density which is 3.9 C. or 39 F., and for engineering work at 53 F., 62.4 lbs. per cu. ft. with some allowance for dissolved air. Reduction to standard conditions being only necessary for exact work, the liquid head system is deservedly widespread. In Metric units, conversion of standard water head to force per area is, of course, convenient.

The absolute unit of force is the dyne, and pressures are expressed in dynes per sq. cm. in scientific work, and also in engineering work on low pressures, for which this unit (close to 1 micron Hg) is convenient; but the dyne per sq. cm. is seldom used in industry. The bar is the absolute unit which would be easiest to work with in industry as its value is close to that of the normal atmosphere. By definition it is equal to one million dynes per sq. cm.

Lastly, the Normal Atmosphere, an international unit. Its value is close to one million dynes per sq. cm., and since it roughly equals also ten meters water head, or 1 kg. per sq. cm.—which takes much longer to say or write in any language—it is growing in acceptance in America, though its spread here cannot compare with the universality of its employment in France (where it originated) and in other countries.

Table I, originally prepared in 1930, by the author with the assistance of the National Bureau of Standards, especially for the first form of this Handbook, gives conversion factors for sixteen pressure units.

4. GENERAL CLASSIFICATIONS OF PRESSURE-MEASURING INSTRUMENTS

Classification by Principles Employed.—According to the principles which they utilize, all pressure-measuring instruments may be divided into two distinct groups:

(1) the primary manometers, any one of which can be constructed and calibrated without reference to another pressure-measuring instrument;

(2) the secondary instruments, that is to say all others, regardless of principle, method, range or form. A gage belonging to the second class can only be calibrated by comparison.

Another broad classification is:

(1) Manometers which depend upon *gravitational* forces for their indication of the measured pressure, and

(2) all others.

"Primary" Manometers—The great majority of these instruments take the forms of single or multiple glass tubes in which a column of liquid is supported by the pressure to be measured, the determination of which is then a matter of measuring the exact height of the visible column and applying corrections when necessary. The result is the value of the measured pressure in units of liquid head. There are several modifications, including inclined tubes, precision manometers, multiple and compound-column types, etc. Another class of primary instruments takes in the various forms of the *closed-column or compression manometer*, in which the measured pressure acts upon a body of gas whose initial volume is exactly known and whose reduced (or greater) volume can be measured exactly. In this case it is necessary, after a considerable change of pressure, to wait until the temperature of the compressed gas falls (or rises) to the initial point, or to correct for temperature differential by Charles' Law, or to use a constant-temperature bath. The measurement of pressure is then a matter of applying Boyle's Law.

The usual form consists essentially of a sturdy glass tube with a graduated closed end. Hydrogen is preferably employed because, outside of its departure from Boyle's Law which is easy to allow for in the calibration, it behaves as a perfect gas within the range of the manometers. Mercury is used to transmit the pressure because other liquids would absorb and contaminate the hydrogen (mercury vapor correction is negligible). A portion of the mercury usually acts as a positive or negative head but this is easy to measure and add or subtract. The barometer reading is added to obtain gage pressure.

The McLeod Gage is a variant, for vacuum work, of the compression manometer.

A sample of the air or gas, whose pressure is to be measured, is admitted without change of pressure into a measuring chamber and an exact volume then sealed off by mercury, after which a known pressure (mercury head, using the same supply) compresses the air or gas into the graduated capillary top of the measuring chamber. Temperature precautions being observed, the original pressure is that fraction of the measured final pressure corresponding to the reciprocal of the volume ratio, plus or minus a correction for departure from Boyle's Law when exact values are desired.

"Primary" Pressure Gages—The usual form consists essentially of a vertical cylinder of exactly-known inside diameter into which fits a piston which can be precisely loaded. The commonest type is the dead-weight gage tester; another type is the fluid-pressure scale.

Liquid-sealed Bells—This principle is likewise "primary" when the pressure is balanced by weights (usually pendulums) and not by springs. In some actual industrial instruments, however, there enter other factors which, though they are in the nature of refinements and conveniences, debar them from admittance to the scientific "primary" group. The same holds true with regard to

"Ring" and "Tilting" Manometers. These are primary in principle but actually embody construction features which, though of distinct industrial value, preclude independent calibration.

"Secondary" Gages—This designation is given here because it is the accepted generic name for all pressure instruments which require calibration by comparison with those of the primary group, but we shall not use it again outside of this present discussion. The fact is that most industrial pressure measuring instruments belong to this group; and the author is convinced that standardization of materials, of dimensions, of heat treatments, etc., has resulted in the availability of individual instruments which can be relied upon. A brief outline of some of the principles employed in "secondary" gages now follows:

Elastic Deformation—Steel, brass, bronze, beryllium-copper, and other alloys are mostly employed for pressure-balancing springs which may be divided into (1) diaphragms, capsular springs, etc.; (2) hollow springs such as Bourdon tubes and helical tubes which deflect; (3) hollow cylinders provided with electrical or optical means of greatly magnifying the slight expansion; and (4) separate springs used in connection with "slack" diaphragms, bellows, etc., as well as with pistons. These separate springs are known as "restraining" or "control" or "calibrated" springs.

Other Methods—Electrical resistance of conductors such as manganin wires, mercury in non-conducting tubes, etc.; electrical resistance of some semi-conductors; electrical conductivity of gases; piezoelectric effects in crystals, gas viscosity and thermal and electrical conductivities (for vacuum work); permanent deformation (in crusher gages for explosion maximum pressures) and boiling temperature of water (in altimeters) are among the other principles utilizable for pressure measurements. Some of the instruments will be described, with emphasis on the practical forms.

"Null" and "Deflection"—As in other fields of measurement, this is an important division. See Ch. I, Part 2, of the 1951 edition of this book. In connection with pressure-measuring instruments, two points may be made briefly: (1) It is obvious that the null principle is utilized in the simplest glass-tube manometers and that complications may disturb the balance. (2) The accuracy, sensitivity and other measuring properties of elastic-member instruments can be improved—improved greatly in many cases—by application of the null principle in such manner that there is practically no deflection of the elastic member. The main reason for these improvements is that hysteresis can be eliminated—or at least minimized. This is why the FORCE-BALANCE PRINCIPLE finds a growing number of applications in the field of pressure instrumentation.

5. INDUSTRIAL CLASSIFICATIONS

The application is the determining factor in the selection of a pressure-measuring instrument, as it is in other industrial measurements. The most obvious classification of applications is according to the range. With this consideration in mind, Table II was conceived and constructed in 1930.

"Indicating, Telemetering, Recording, Controlling" is a familiar functional classification. It is, of course, a classification of entire systems, not of pri-

mary elements. In view of the rich variety of pressure-instrument components available today, the choice of particular designs (or particular makes) of final elements need not dictate the selection of undesirable types of primary elements.

This rule is fairly obvious when the final elements are physically remote from the primary elements. This rule holds true also when it does not seem obvious; when the primary element and the final element are to be close to each other inside one housing.

Speed or Frequency Classifications—In practice, speed or frequency classifications are of interest mainly with reference to separate recording systems. For example, undistorted records of explosion phenomena ordinarily preclude the use of a mechanism such as a pen-arm ending in an ink reservoir and writing on paper; and dictate the use of an optical lever (or of a beam of electrons) recording on a photographic emulsion.

However, the primary measuring element must be fast enough for the intended purpose and so must the intermediate element which converts (for example) the deflection of an elastic member into a change of air pressure (pneumatic telemetering), or into a change of voltage, current or frequency (electric telemetering), or into a change of megacycle frequency (radio telemetering). The fastest of all primary pressure-responsive elements are still in the laboratory stage at the time of writing: they are rather complicated arrays for photographing on fast-moving films the molecular, atomic and ionic phenomena associated with pressure. Almost equally fast, however, are some electrical methods.

Static and Differential—Another important industrial distinction is between instruments designed for the measurement of one pressure, and those for the measurement of differential heads. In the case of the latter instruments, an important industrial consideration is that such instruments, while measuring a differential which may be small, must at times—and at the same time—withstand a high static pressure.

Variability—Few pressures requiring measurement in industry are so steady that variations can be ignored in the selection of instruments. Most industrial gages, as a matter of fact, have been designed with a knowledge of this, and not only withstand the variations usually present but give readings which are at least reliable if not extremely accurate. But some pressures vary regularly in cycles; while others fluctuate irregularly, much or little, rapidly or slowly. For exact measurement, then, there must be provided either some correct method of damping, or some means of obtaining a record.

The Appearance Factor also emerges as a modern criterion in classifying pressure instruments. It takes in size, shape and mounting, which are not to be ignored when laying out a control board, for example; as well as a due regard to convenience and human efficiency—"readability," illumination, etc.

These practical considerations completely overshadow the question of whether or not an instrument "can be constructed and calibrated without comparison with another pressure measuring instrument." The tables in this chapter are designed accordingly to serve as practical guides by giving the characteristics of practical importance.

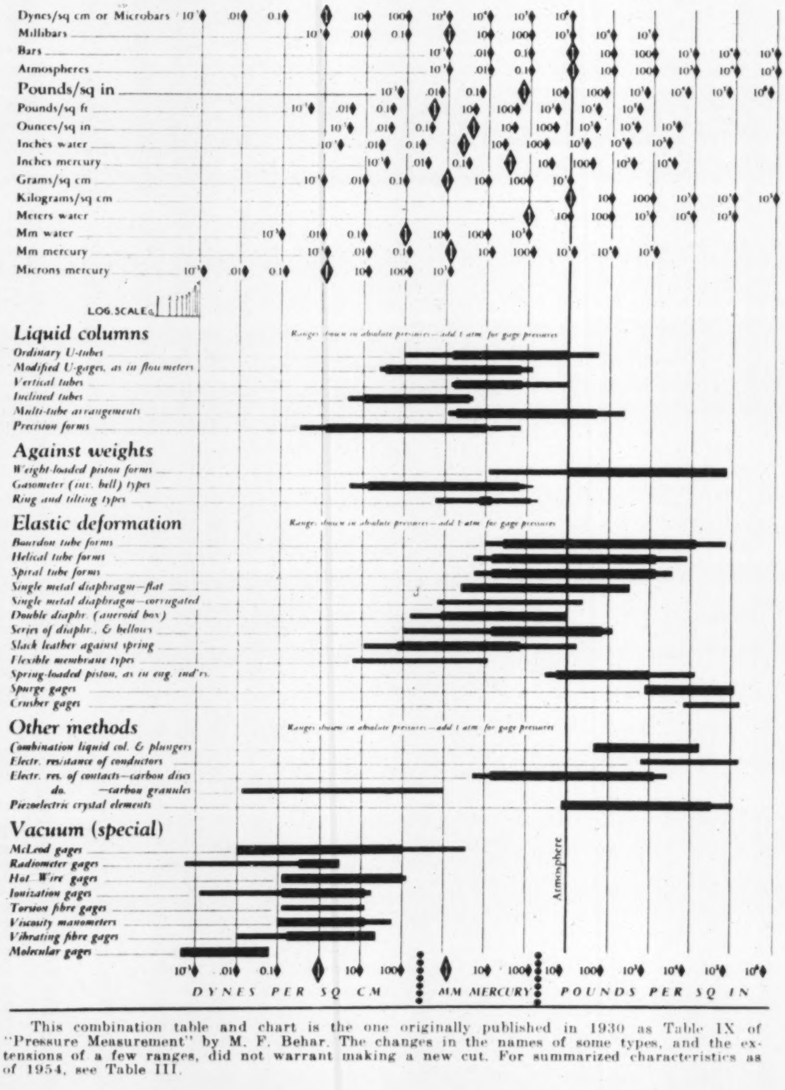
6. LIQUID COLUMNS—GENERAL

The principle involved in using liquid columns is to oppose the pressure by liquid head, which varies not only with the height of the column but with two principal factors: (1) the variation

TABLE II—PRESSURE-MEASURING INSTRUMENTS—RANGES OF APPLICABILITY OF THE CLASSES AND TYPES

and a Chart of Orders of Magnitude of Pressure Units

Notes—(1) Graphic pressure scale is logarithmic: each vertical line denotes ten times the value of the line at its left. (2) Scales of units extend only over pressures with which they are ordinarily used. (3) Ranges shown opposite types of instruments are those within which such types can be employed for measurement. Heavy portions indicate agreement of sources of information as to suitability. Lighter portions extend over pressures for which such suitability (or the availability of instruments) has been questioned.



This combination table and chart is the one originally published in 1930 as Table IX of "Pressure Measurement" by M. F. Behar. The changes in the names of some types, and the extensions of a few ranges, did not warrant making a new cut. For summarized characteristics as of 1954, see Table III.

of the density of the liquid with temperature and (2) the variation of gravitational force with latitude and elevation. These two corrections are necessary because liquid-head units imply standard values of liquid density and gravity. In addition, there are needed corrections for factors that affect the actual measurement: (3) capillarity or meniscus and (4) thermal expansion of the scale. For high-precision work, two more factors are: (5) absorbed gases and (6) compressibility. This section gives miscellaneous generally-applicable data. Mercury and water being the liquids on which head units are based, these data refer principally to mercury and water columns. Section 7 considers the special case of the mercurial barometer.

Temperature Corrections

For short columns, temperature corrections are often considered to be negligible, except in precision manometers. Inasmuch as the graduated metal scale, by means of which a liquid column is most frequently measured, also expands and contracts with temperature changes, the correction may be for differential expansion, whence the origin of the expression "Brass Scale," the standard brass scale being correct at 62 F. The brass scale correction is included in the Weather Bureau barometer-correction tables.

Water Column Corrections—A column of pure water exactly ten inches high at 68 F. will be 0.017 in. shorter at 39 F. and 0.052 in. longer at 100 F. At 70 F. it would be only 0.0022 in. longer and therefore this temperature correction need not be applied in ordinary work when the water standard is 60 F. and the column is at ordinary room temperature. When reduction to the Standard Temperature, 39 F. or 4 C., is desired, use Table IV (based on the mass of 1 cc. of water at 4 C. being taken as unity and the absolute density in cgs. units being obtained by multiplying the relative density by 0.999973), or Table V which gives convenient factors.

Mercury Columns—Table VI gives temperature corrections for mercury columns up to 32 in. For any mercury column an easily remembered shortcut is the "Ten Thousand" formula: to reduce the column to 32 F., multiply the height of the column by the Fahrenheit temperature above 32, and divide by 10,000; then subtract the result from the exactly measured height.

Other Liquids—Exact work is usually done with water or mercury, but other manometric liquids are used in many applications by reason of low freezing points, etc. Their coefficients are given in Table XI.

Gage and Absolute Pressures.

For pressures below atmospheric, and for exact work when gage pressure is less than, say, 50 psig, absolute pressures should always be determined by reference to the barometric reading

TABLE III—QUICK-REFERENCE DATA ON PRESSURE-MEASURING INSTRUMENTS

CLASS	TYPE	CHARACTERISTICS		
		Optimum Range*	Accuracy†	Other Characteristics (Footnotes explain symbols)
U-Tube	Glass—mercury	0.5-50"Hg	0.02"	Ga Di *Co* **In** *Sd* **Sy** **Vb**
	Glass—water	0.5-100"H_2O	0.02"	Ga Di **In** **Sy** **Vb**
	Glass—two-liquid	0.01-1"H_2O	0.5%	Ga Di Dr **In** **Sy**
	Float, electric, etc.	0.5-50"Hg	0.05"	*Ga* Di Co Re **RR** Sy Vb
	Multiple-tube	10-100'Hg	0.5%	*Abs* Ga **In** Sd **Sy**
Single tube	Vertical—open top	2-100"Hg	0.02"	Ga **In** Ru Sv **Vb**
	Compression manom.	vac.-200 psi	1%	Abs *OV* **In** Sy
	Open-cistern vac. gage	0-30"Hg	0.02"	Abs OV **In** *Sd*
	Mercurial barometer	Atmospheric	0.01"	**In** *Sd*
	do., photocell servo	Atmospheric	0.005"	*Re* RR Sd **Sy**
	Abs. pressure gage	0-100"Hg.abs.	0.005"	Abs. OV **In** Sy
	Inclined-tube	0-4"H_2O	0.005"	Ga OV Dr **In** **Sy**
Micromanometer	Null method, etc.	0.001-20"H_2O	0.05%	Ga OV **In** **Sy**
Liquid col. & plunger	Mercury	50-5000 psi		Ga **In** Ru
Weight-loaded piston	Dead weight	-100,000 psi	0.1%	**Ga** **In** Ru Sd
	Fluid pressure scale	50-8000 psi	0.2%	**Ga** **In** Ru Sd
	Pendulum	100-8000 psi	0.2%	**Ga** *Co* *Sd*
	Automatic balance	200-1000 psi		**Ga** *Co* Re **RR**
Liquid-sealed bell	Oil sealed	0.1-10"H_2O	1%	Ga Dr *Di* *Co* Re Sy
	Mercury sealed	0.1-10"Hg	1%	Ga Dr *Di* *Co* **Re** Sy
Tilting	Ring, etc.	0.1-10"Hg	2%	Ga Dr Di Re RR **Sy**
Tube-spring	Single Bourdon	10-30000 psi	2%	Ga OV *Co* *Re* **Ru** Vb
	do., elec. trans.	10-3000 psi	2%	Ga OV Re **RR** **Ru** *Va* *Vb*
	do., pneu. trans.	10-3000 psi	2%	Ga OV Re **RR** **Ru** *Va* *Vb*
	do. "Inspector's"	10-5000 psi	0.5%	Ga **In** Sd
	Double Bourdon	50-800 psi	2%	**Ga** **Ru** Vb *Co*
	Helical	5-500 psi	1.5%	**Ga** *Co* Re *RR* **Ru**
	Spiral	10-1000 psi	1.5%	**Ga** *Co* Re **Ru**
Diaphragm (Metallic)	Unloaded, flat	1-200 psi	1.5%	Ga OV *Co* Re Ru ***Va*** ***Vb***
	Unloaded, corrugated	0.5-50 psi	2%	Ga OV Dr Co Re ***Va***
	Spring-loaded	2-200 psi	1%	Ga OV *Co* Re Ru ***Va***
	do., strain-ga. trans.	50-1500 psi	1%	Abs Ga OV Di **Os** **RR** **Vb**
	do., pneu. trans.	vac.-300 psi	0.5%	*Abs* Ga OV Dr **RR** **Va** **Vb**
Membrane (leather, fabric, plastic, etc.)	Spring-loaded	0.2-100"H_2O	1.5%	Ga Dr Di *Co* Re Sy
	do., elec. trans.	0.1-50"H_2O	1.5%	*Abs* Ga Dr *Di* Re **RR** ***Va***
	do., pneu. trans.	0.1-40"H_2O	1.5%	Ga OV Dr *Di* Re **RR** ***Va***
Bellows	Unloaded	1-100"H_2O	2%	Ga OV Dr Di Co Re ***RR*** **Sy**
	Spring-loaded	0.5-200 psi	2%	**Ga** **OV** Dr *Co* Re *RR*
	do., elec. trans.	0.5-50 psi	1%	**Abs** **Ga** OV Di **RR** **Va** ***Vb***
	do., pneu. trans.	0.1-100 psi	1%	Abs Ga OV Di **RR** **Va** ***Vb***
	Pendulum-loaded	10-200"H_2O	2%	Ga OV Dr *Co* Re Sy
Capsular spring	Unloaded	1-50"H_2O	3%	*Abs* Ga OV *Di* Ru ***Va*** **Vb**
	Aux. spr. loaded	0.5-100 psi	2%	*Abs* Ga OV *Di* Ru ***Va***
	Null method	Atmospheric	0.1%	**In** Sd
	Aneroid barometer	Atmospheric	0.2%	Re *RR*
Electrical	Carbon pile, etc.	50-2000 psi	2%	**Ga** **Os** Re **RR** Ru **Vb**
	Crystals	100-20000 psi	2%	**Ga** **Os** Re **RR** **Vb**
	Electromagnetic	5-10000 psi	2%	Ga Re **RR** Ru Va
	Manganin, etc.	1000 atm.up	3%	**Ga** **Os** Re **RR** **Ru** **Vb**
VACUUM		MICRONS		
Liquid column (compression manom.)	Laboratory McLeod	0.01-2000	2%	**In** Sd **Sy**
	Industrial McLeod	0.1-100,000		*Co* *Re* *RR* **Sy**
Viscosity or molecular	Strictly lab. types	0.0001-100		**In** **Sd** **Sy**
	Field (milit. research)	1-760,000		Co *Os* Re RR Ru Va
	Industrial	10-760,000		In *RR* Ru Sy *Va*
Radiometer	Knudsen	0.0001-1		**In** *Sd* **Sy**
	Aluminum vane	0.00001-1		**In** *Sd* **Sy**
	Aluminum leaf	0.1-100		**In** *Sd* **Sy**
Conductivity	Thermocouple	1-500		Re RR *Va*
	Resistance (Pirani)	1-250		Re RR *Va*
	do. semiconductor	1-1000		Re RR *Va*
	Wire length	0.01-100	—	*Co* *Va*
Ionization	Thermionic	0.00001-10		Re RR *Va*
	do., fluores. indic.	5-2000		**In** **Va**
	Cold (Philips)	0.01-1000		Re RR Ru *Va*
	do., glow indic.	0.1-1000		**In** **Va** Ru
	Alpha-particle	1-10,000		*Re* *RR* *Va*
Elastic-member	Unloaded	10-10,000		*Co* *Va* *Di*

*Not scale range but LIMITS between which the type is preferably employed.

†Average accuracy of MOST commercial models. Some types are available in high-precision grades.

Bold-face type signifies that remark applies to ALL instruments of this type.

Italics signify that remark applies only to ***SOME*** instruments of this type.

Symbols in plain roman type apply to majority of instruments.

Abs	Suitable for measurement of absolute pressure.
Ga	Preferably used for measurement of gage pressure (above atmospheric).
OV	Suitable for measuring ordinary vacuum (negative pressure below atmospheric).
Dr	ditto, especially for draft.
Di	Suitable for measuring differential head, as in flow measurement.
Co	Contact arrangements or other on-off pickups available for signaling, etc.
In	Indicating only—No recorders on market.
Os	Can actuate oscillograph for study of extremely rapid fluctuations.
Re	Recording models available.
RR	Remote-reading systems commercially available.
Ru	Rugged construction of primary pressure-sensitive element.
Sd	Suitable for use as Plant Standards.
Sy	For steady pressures only (opposite of Os.).
Va	Suitable for exact measurement of moderately variable and fluctuating pressures.
Vb	Withstand severe vibrations.

at the time of measurement and elevation of apparatus.

Gravity Correction

Inasmuch as the attraction between the earth and a body of a given mass decreases as the square of the distance from the center of mass of the earth to the c.-m. of the body, any system of weights must be based on an accepted standard value of the gravitational acceleration. In pressure measurement with instruments that balance pressure against gravitation, the particular location—with regard to latitude and to elevation above mean geodetic datum—may have to be allowed for. Table VII gives the corrections in terms of heights of columns in inches, but the same proportional factors may be used for any linear units. (The value of g, 980.665 cm./sec.^{2}, is the internationally accepted standard value. The exact notation g_s is sometimes given to distinguish it from g_{45} which has the value of 980.616).

Meniscus Correction

This should come first in practice because without it the casual "observation" is not "the reading" of the column, desired in close work. The phenomena of capillarity are familiar. Opposite effects occur when a liquid wets a solid as in the case of water and clean glass (Fig. 2, a); and when a liquid does not wet a solid as in the case of mercury and glass (b). The curved surfaces are known as menisci. A meniscus surface should always be read at its center—the bottom in the case of water and the top in the case of mercury—before applying the correction. The rise (water) or depression (mercury) is most pronounced in the case of small-bore tubes.

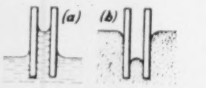


Fig. 2

For water and clean glass the rise amounts in inches to $0.046/d$ where d is the inside diameter in inches. Thus, for a tube with an internal diameter of 0.046 in., the water would stand one inch higher than the outside surface. It is commonly believed that this effect cancels out entirely in a U-gage, but that is true only if the inside diameters of the two legs are alike. For example, in a U-tube with the diameter of one leg ⅛ in. plus 0.01 in. and that of the other ⅛ in. minus 0.01, the water stands 1/16 in. higher in the smaller tube.

For mercury meniscus and capillarity corrections, see Table VIII.

Capillarity rise or depression becomes negligible when the internal diameter of a tube is greater than half an inch. Thus, for a ½-in. tube, the visible meniscus height may be divided by about 11 to obtain the correction with reference to the center surface of the meniscus.

TABLE IV—EFFECT OF TEMPERATURE ON WATER COLUMNS

°F	*°C*	*Density*	*Length of Column*
32	0	0.99987	1.00013
39	4	1.00000	1.00000
50	10	0.99973	1.00027
59	15	0.99913	1.00087
68	20	0.99823	1.00177
77	25	0.99707	1.00294
86	30	0.99567	1.00435
95	35	0.99406	1.00598
104	40	0.99224	1.00782
113	45	0.99025	1.00985

TABLE V—DENSITY OF WATER AND MULTIPLIERS FOR WATER COLUMNS

Temp. deg. F.	Density of water, lb. per cu. ft. *d*	Multipliers for reducing readings in inches of water column to Lb. per sq. in. (d/1728)	Multipliers for reducing readings in inches of water column to In. mercury at 32 deg. F. (0.01178 d)
32	62.42	0.03614	0.07354
35	62.42	0.03614	0.07354
40	62.42	0.03614	0.07354
45	62.42	0.03614	0.07354
50	62.41	0.03613	0.07352
55	62.39	0.03611	0.07350
60	62.37	0.03609	0.07348
65	62.34	0.03607	0.07344
70	62.31	0.03606	0.07341
75	62.28	0.03604	0.07337
80	62.23	0.03601	0.07331
85	62.18	0.03598	0.07325
90	62.13	0.03595	0.07320
95	62.08	0.03592	0.07314
100	62.02	0.03589	0.07306

Correction for Different Atmospheric Level—The correction given in Table X, for exact work as in important tests, is for difference between the atmospheric pressure at the level of the measured pressure vessel and the atmospheric pressure at the level of a gage or open-column manometer influenced by atmospheric pressure.

The correction is found by multiplying the value given in the table by the difference in elevation in feet, divided by 100. The correction is applied to the gage reading as follows: For a gage reading below atmosphere, and set at a low elevation; subtract. For a gage reading above atmosphere, set at a low elevation; add. For a gage reading above atmosphere, set at a high elevation; subtract.

Coloring Water Columns—Add a few drops of one percent alcoholic solution of fluorescein to a liter or quart of water. The dilute solution of fluorescein is bright green by reason of its fluorescence, although colorless by transmitted light. A small quantity of aqueous (1%) solution of uranine (the sodium salt of fluorescein) may be used in place of the alcoholic solution mentioned above.

If solutions showing color by transmission are desired, dilute aqueous may be made with any of these dyes:

Dye	*Color*
Erythrosine	Pink
Eosine	Pink (green fluorescence)
Rhodamine B	Pink (red fluorescence)
Ponceau 2R	Scarlet
Napthol green	Green
Methylene green	Bluish green
Methylene blue	Blue
Methyl violet	Purple

Carbon bisulphide may be colored with iodine.

Alcohol has to be colored when it is used against kerosene in sensitive differential-density or two-liquid U-gages. A number of anilin dyes insoluble in kerosene are on the market.

Purification of Mercury

For precision work, the errors caused by dirty mercury are relatively enormous. Mercury must be periodically purified when it is not in a hermetic

TABLE VI—TEMPERATURE CORRECTIONS FOR MERCURY COLUMNS UP TO 32 INCHES

Temp. of column, deg. fahr.	Observed reading of column in inches of mercury 16	18	20	22	24	26	28	30	32
				Add					
-20	0.07	0.08	0.09	0.10	0.11	0.11	0.12	0.13	0.14
-10	0.06	0.06	0.07	0.08	0.08	0.09	0.10	0.11	0.11
0	0.04	0.05	0.05	0.06	0.06	0.07	0.07	0.08	0.08
10	0.03	0.03	0.03	0.04	0.04	0.04	0.05	0.05	0.05
20	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02
30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
				Subtract					
35	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02
40	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.03	0.03
45	0.02	0.03	0.03	0.03	0.04	0.04	0.04	0.04	0.05
50	0.03	0.03	0.04	0.04	0.05	0.05	0.05	0.06	0.06
55	0.04	0.04	0.05	0.05	0.06	0.06	0.07	0.07	0.08
60	0.05	0.05	0.06	0.06	0.07	0.07	0.08	0.08	0.09
65	0.05	0.06	0.07	0.07	0.08	0.09	0.09	0.10	0.10
70	0.06	0.07	0.07	0.08	0.09	0.10	0.10	0.11	0.12
75	0.07	0.07	0.08	0.09	0.10	0.11	0.12	0.13	0.13
80	0.07	0.08	0.09	0.10	0.11	0.12	0.13	0.14	0.15
85	0.08	0.09	0.10	0.11	0.12	0.13	0.14	0.15	0.16
90	0.09	0.10	0.11	0.12	0.13	0.14	0.15	0.17	0.18
95	0.10	0.11	0.12	0.13	0.14	0.16	0.17	0.18	0.19
100	0.10	0.12	0.13	0.14	0.15	0.17	0.18	0.19	0.20

TABLE VII—CORRECTION OF MERCURY COLUMNS TO STANDARD GRAVITY

North latitude degrees	Elevation, feet: 0	0	2000	2000	4000	4000	6000	6000
	Height of column, inches of mercury: 30	28	28	26	26	24	24	22
25	—0.05	—0.05	—0.05	—0.05	—0.05	—0.05	—0.06	—0.05
30	—0.04	—0.04	—0.04	—0.04	—0.05	—0.04	—0.05	—0.04
35	—0.03	—0.03	—0.03	—0.03	—0.03	—0.03	—0.04	—0.03
40	—0.02	—0.01	—0.02	—0.02	—0.02	—0.02	—0.03	—0.02
45	—0.00	—0.00	—0.01	—0.01	—0.01	—0.01	—0.01	—0.01
50	+0.01	+0.01	+0.01	+0.01	—0.00	—0.00	—0.00	—0.00

TABLE VIII—MERCURY MENISCUS OR CAPILLARITY CORRECTIONS

Not to be used with barometers, where the meniscus correction is allowed for in the setting of the scale. The correction is in inches and is to be added to the reading of a mercury column comprising a single leg and a reservoir of appreciable area. The table can be used also for a mercury U-tube with legs of different diameters. The reading is to be taken at the top of the meniscus.

Internal diameter inches	Height of meniscus in inches 0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08
	Correction in inches to be added							
0.15	0.024	0.047	0.069	0.092	0.116		. . .	. . .
0.20	0.011	0.022	0.033	0.045	0.059	0.078	. . .	. . .
0.25	0.006	0.012	0.019	0.028	0.037	0.047	0.059	. . .
0.30	0.004	0.008	0.013	0.018	0.023	0.029	0.035	0.042
0.35	. . .	0.005	0.008	0.012	0.015	0.018	0.022	0.026
0.40	. . .	0.004	0.006	0.008	0.010	0.012	0.014	0.016
0.45	. . .	. . .	0.003	0.005	0.007	0.008	0.010	0.012
0.50	. . .	. . .	0.002	0.004	0.005	0.006	0.006	0.007
0.55	. . .	. . .	0.001	0.002	0.003	0.004	0.005	0.005

TABLE IX—AVERAGE ATMOSPHERIC PRESSURES AT VARIOUS ALTITUDES

Altitude, above sea level feet	*Average atmospheric pressure,* Inches of Mercury at 32 deg. F.	Lb. per sq. in.
0	29.92	14.70
1,000	28.85	14.17
2,000	27.82	13.67
3,000	26.82	13.17
4,000	25.84	12.69
5,000	24.90	12.23
6,000	23.98	11.78
7,000	23.09	11.34
8,000	22.23	10.92
9,000	21.39	10.51
10,000	20.58	10.11
12,000	19.03	9.35
14,000	17.57	8.63
16,000	16.21	7.96
18,000	14.93	7.33
20,000	13.74	6.75

TABLE X—CORRECTIONS FOR BAROMETERS AND PRESSURE GAGES, IN INCHES OF MERCURY FOR DECREASE OF ATMOSPHERIC PRESSURE PER 100 FT. INCREASE IN ELEVATION

Mean altitude, in feet	Mean atmospheric temperature, deg. fahr.						
	-20	0	20	40	60	80	100
0	0.13	0.12	0.12	0.11	0.11	0.10	0.10
1000	0.12	0.12	0.11	0.11	0.10	0.10	0.10
2000	0.12	0.11	0.11	0.10	0.10	0.10	0.09
3000	0.11	0.11	0.10	0.10	0.10	0.09	0.09
4000	0.11	0.10	0.10	0.10	0.09	0.08	0.08
5000	0.10	0.10	0.10	0.09	0.09	0.08	0.08
6000	0.10	0.10	0.09	0.09	0.08	0.08	0.08
7000	0.10	0.09	0.09	0.09	0.08	0.08	0.08

TABLE XI—MEAN COEFFICIENTS OF CUBICAL EXPANSION PER DEG. FAHR. OF MANOMETRIC LIQUIDS

Liquid	*M.P.,F.*	*Sp. Gr.*	*Mean Coeff.*
Water	32	1.0000	.000115
Mercury	– 38	13.570	.000101
Acetone	–138	0.792	.00162
Alcohol (ethyl)	–179	0.7939	.000600
Alcohol-glycol	– 60	1.0000	.000427
Benzene (benzol)	42	0.8794	.000687
n-Butyl Phthalate	– 31	1.0477	.000433
"Ellison Gage Oil"		0.8340	.000466
Ethylene Glycol	0.8	1.1155	.000354
Glycerine (glycerol)	64	1.260	.000281
Kerosene	– 20	0.820	.000480

enclosure of glass (or other absolutely neutral material) which had been thoroughly cleaned.

Fortunately, even slight contaminations foul the meniscus, thereby providing a warning before the mercury's density has become appreciably altered. But the warning must be heeded when it appears!

Four common methods are in vogue for purifying dirty mercury: (1) distillation, (2) filtration, (3) agitation with air, and (4) washing with acid or alkali solution.

7. LIQUID COLUMNS—MERCURIAL BAROMETRY

For complete data see the publications of the U. S. Weather Bureau (especially Circular F, price 15 cents), of the National Bureau of Standards, of the National Advisory Committee of Aeronautics and of military and civilian aviation bodies. Data can also be found in the Smithsonian Meteorological Tables, the Smithsonian Physical Tables, the International Critical Tables, etc. For an engineering treatment, see Chapters 1 and 6, Part 2, Instruments and Apparatus, A.S.M.E. Power Test Codes.

Modern mercurial barometers embody numerous refinements, chiefly designed to minimize the temperature error. Fig. 3 shows an airport barometer which is thermostated without affecting barometric sensitivity. A photoelectric follow-up commands a cyclometer register, thereby making the instrument direct-indicating to the thousandth of an inch.

8. ELIMINATING CONNECTION ERRORS —OPENINGS

When a body of fluid is in motion, the location and arrangement of the pressure opening must be studied carefully. The opening should be sufficiently large so that there are no large lags in response. Static pressure holes should be from ¼ to ¾ inch in diameter. The character of the conduit in the neighborhood of the opening should be such that the flow is parallel to the wall. The hole should be at right angles to the wall, and there must be no burrs, jagged edges, or extension of the connecting pipe into the stream.

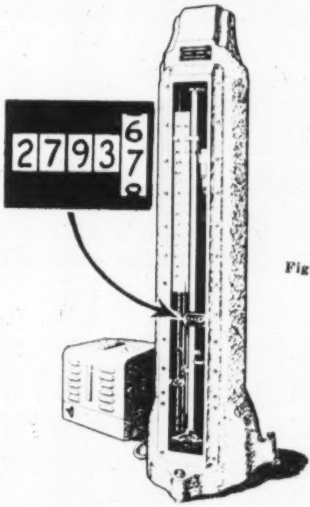


Fig. 3.

A *static tube* is occasionally used to obtain the static pressure of a fluid at rest or in parallel flow. The tube is an L-shaped tube with a closed end and a number of holes on each side. The short closed-end section is inserted into the fluid stream parallel to the stream, and the static pressure of the fluid is transmitted through the holes to the measuring device.

An *impact tube* is a tube with an open end pointing directly upstream. The pressure developed in the tube is total pressure—that is, static pressure plus the pressure equivalent of velocity head. It should be inserted into the conduit so that the open end is at a distance equal to 0.15 of the conduit diameter from the wall. Lengths of straight conduit should precede and follow the impact tube in order to prevent wrong-direction errors.

The foregoing refers to gage-pressure measurement. For *vacuum measurement,* (1) the connection must be as short and large-diameter as practicable; (2) in order to measure the true static pressure when high-speed pumps are used, the mouth of the tubulation must point at right angle to the direction of flow; otherwise—as B. B. Dayton demonstrated—the vacuum gage may read too low or too high by as much as 30%; (3) the connection must, in some cases, include means of trapping contaminants which might cause the vacuum gage to read as much as 25% too low or 100% too high.

9. ELIMINATION OF CONNECTION ERRORS —CONNECTING LINES

Any flow in the line connecting the pressure opening and the measuring instrument may cause errors in readings. Too long a connecting pipe produces lag in response. If the pipe is liquid filled, dynamic effects may cause enormous errors in two ways: (1) at resonance, pressure variations may be magnified five, or even fifty, times so that the chart record will show false spikes; (2) conversely, relatively rapid pressure fluctuations may be attenuated by more than 90% so that the oscillogram will be almost a straight line. A gas-filled connection of relatively large volume (which requires considerable inflow and outflow at every pressure variation) becomes a source of serious error when this in-and-out flow disturbs the parallel flow in the conduit (or in the atmosphere) at the very point where it must not be disturbed.

For gage pressure or differential, the connecting pipe should have no traps. For air and gas it should slope downward from the main to the measuring instrument; for liquid the connecting pipe should slope upward. Rubber tubing can be used for low vacuum or pressure up to about 20 psi. Copper tubing can be used for moderate pressures. Glass or plastic tubing can be used to make liquid or gas pockets visible.

It is essential that the exact contents of the pipe be known, whether air, liquid, or gas, and that there be no pockets. Bleeders can be used to eliminate pockets.

10. PLANT STANDARDS

It is necessary to calibrate all gages periodically. The frequency is a matter of judgment and experience. The designation "Plant Standards" covers gage testing and calibration apparatus designed to serve as accessible reference standards.

Among the plant standards are instruments which can either be used for calibrating gages, or themselves serve as gages when utmost accuracy is required, beyond all doubt. Such instruments are liquid-column micromanometers, dead-weight gages and fluid pressure scales. It is important to note that even slightly fluctuating pressures cannot be measured directly by such instruments. Their principal use, therefore, is to test, check and calibrate gages. This function is made possible by provisions for building up interior pressure within the system of the instrument, and holding definite pressures within narrow limits. For negative pressures (below atmospheric), liquid columns may serve as plant standards if precautions advocated in Section 6 are observed carefully.

(a) Test Pumps

One essential is a pump for creating the pressure applied simultaneously to the gage under test and to the standard. There are on the market several forms especially made for this purpose. In general they consist of a cylinder down which a plunger is forced by a threaded piston rod attached to a handwheel.

(b) Testing Outfits with Precision Comparison-gages

These well-known outfits consist essentially of a pump to be connected to the gage under test and to a high-grade master or "inspector's" gage.

(c) Liquid-column Gage Testers

Direct comparison with a known liquid head is the principle utilized in these testers. Liquid columns can be used to produce a known gage pressure above atmospheric, or a known negative pressure or vacuum. In the latter case the transmitting medium is rarefied air, so that it makes no difference at what level the center of the gage under test may be. In the case of low-pressure gage testers the head is the difference of the two levels of the mercury (or of the water). Therefore it is important to exclude liquid between the lower level and the gage under test, and to transmit the differential by the medium of air.

Atmospheric pressure is not a factor: it acts equally on the open liquid surface and on the outside of the elastic member of the gage under test.

Mercury should be of the highest purity; and water either air-free or of known density. Scales and reference points should be accurate and should be handled carefully when adjustments are necessary. Zero-level adjustment is provided in the cistern types.

(d) Dead-weight Gage Testers

The principle of the dead-weight gage tester is the same as that of a balance: Gravity, acting on calibrated weights, provides the known force. This force being exerted on a known area, a known pressure exists throughout the fluid contained in the system (a suitable oil). Extreme accuracy is possible but requires several factors for its attainment, among them:

1. Known Piston and Cylinder Diameters.

2. Known Weights.

3. Gravity Corrections. If the weights are standardized before being shipped to the locality where the tester is to be operated, a gravity correction may be necessary. For values, see Table V. The best procedure is to calibrate the weights at the locality itself or nearby.

4. Buoyancy. Each of the weights displaces its volume of air. The weight of the displaced air varies inversely as barometric pressure. This effect is allowed for in precision work only.

5. Absence of Friction. In the simpler testers, rotating or oscillating the piston eliminates almost entirely the friction effects and the friction errors of calibration are eliminated by prescribed methods of gage calibration which involve taking "ascending" and "descending" readings.

6. Head of Transmitting Fluid. In low-pressure calibration, the difference of level between the piston and the surface of the oil below the gage has an appreciable effect.

7. Method of Operation. The most important thing is to keep the piston floating in mid-position, and either spinning or oscillating.

(e) Fluid-pressure Scales

The principle is similar to that of the dead-weight gage. Pressure is built up by a screw plunger and is transmitted hydraulically to the gage under test and to the moving piston. This piston, however, actuates a scale beam, whence the name.

(f) Pendulum Manometers

The pendulum-loaded piston gage, commonly called pendulum manometer, differs from the fluid pressure scale in that the load varies as the sine of the pendulum's angle plus constants and geometric factors. These are capable of exact predetermination so that the instrument is theoretically a "primary" gage. One advantage of the pendulum principle is that the sensitivity (i. e., the "unit sensitivity") automatically varies with the order of magnitude of the measured pressure.

11. MEASUREMENT OF FLUCTUATING PRESSURE

For measuring unfluctuating or slowly fluctuating pressures, the speed of response and other dynamic characteristics of the pressure-sensitive system can usually be ignored. However, when measuring rapidly fluctuating pressures, the response characteristics of the system must be considered. The most important characteristics are the *natural resonant frequency* and the *damping* (see Chapter XII).

The first system component to consider is the primary element—not the entire pickup assembly with its housing but, specifically, the parts that are deformed or *displaced* by pressure changes.* Ideally, they should be weightless in order to be inertialess. In practice they are often made relatively inertialess by being made small. But, since pressure is force per area, a "point" or "dimensionless" element is an absurdity for pressure measurement; it must occupy an area; therefore the ideal element is two-dimensional. The obvious answer is thinness. But—a soap-bubble-like diaphragm, even if ideally elastic, is so delicate that it can only measure extremely small pressure changes. So, in practice, the solutions usually consist in careful choices of strong, light, elastic *materials* for diaphragms, Bourdon tubes, loading springs, etc.

How much primary-element displacement for ideal recording of rapid fluctuations and transients? No universal answer; every solution a compromise. On the one hand, inflow and outflow effects may distort the true picture of the fluctuation (or shock-wave, etc.). On the other hand, an absolutely rigid pickup may likewise alter the phenomenon under study ("wall effect," cavity resonance, etc.).

Force times displacement equals WORK. Work is alternately done *upon* and *by* the moving system. Hence the desirability of perfect elasticity and frictionlessness in order to achieve equality. If the element does not return all the energy it stores at every cycle—if it absorbs or dissipates energy—the true record will be distorted by *hysteresis;* and the "lost" energy, as *heat,* may alter the calibration and otherwise cause trouble.

Thus, considering only the primary element, it sometimes is found that a relatively heavy device (say a magnetostriction bar or piezo crystal stack) best serves the particular purpose; and sometimes a relatively light spring-loaded piston that travels a full inch.

Although the primary pressure-sensitive element is the first thing to be considered, the rest of the system, including the recorder marking mechanism, can produce errors by being unable to follow the pressure variations rapidly and accurately. The effect of the resonance of a pressure-sensitive system is shown in Fig. 4. The small high-frequency "ringing" oscillations are caused by the natural resonance of the system. They can be caused by the primary element, the transmission line, the recorder, or any part of the system which must respond to the impulse.

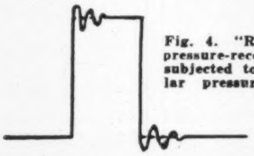


Fig. 4. "Ringing" of a pressure-recording system subjected to a rectangular pressure impulse.

In order to follow a rapid change, the pressure-sensitive element must be rigid and rigidly connected to the rest of the system. As rigid objects and systems have high natural frequencies of resonance, this is the same as saying that the resonant frequency should be as high as possible. However, rigid elements do not move far. Therefore, the sensitivity of rigid primary elements is low. Obviously, a compromise must be made. In practice, an element is used whose natural resonant frequency is several times the highest important frequency to be recorded.

Damping is used to reduce the undesired oscillations produced by the natural resonance. However, damping produces a phase lag between the impulse and the response—that is, damping causes the damped element to lag behind the driving impulse. Therefore, only enough damping is used to minimize the resonant oscillations without introducing excessive phase lag. The phase-lagging effect of damping is small when the natural resonant frequency is much higher than the impulse frequencies. This is another reason why the dynamic response characteristic of the system should include as high a frequency of natural resonance as is consistent with sensitivity.

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*This discussion is limited to elastic-deformation elements, including piezoelectric crystals, maganin wires, etc. We omit here the dynamic response of liquid columns, etc.

PART 2—PRESSURE-MEASURING INSTRUMENTS

1. GRAVITATIONAL—LIQUID COLUMNS

(a) *U-tube Types*

For the measurement of single pressures with one leg open to atmosphere, there are various syphon models with a riser longer than the U and connected to the top of the pressure leg. Most glass tubes are protected. In many models the glass bend—a weak spot—is done away with and there are robust top and bottom headers in the design of which considerable ingenuity is displayed. Matched pairs of tubes—same internal diameter and uniform bores—prevent capillary errors that arise from the combination of evenly-graduated scales with non-uniform tubes. This is especially important in long columns. In some of these, the readings are taken from a scale the upper end of which is attached to a rider which slides on the glass tubes and is adjusted to the level of the upper column (right tube), the lower rider being similarly adjusted to the left tube, having a vernier which permits readings to 0.01 in. The difference in the column heights can be read directly. In some designs, air-bind is eliminated by being able to fill the gage through the bottom. Venting valves permit removal of any air which might become trapped at the top.

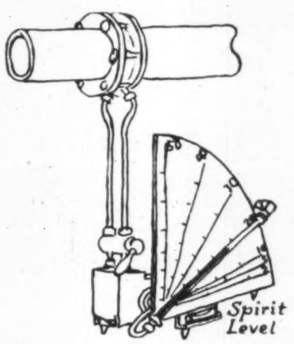


Fig. 5.

Another instrument for hydraulic differentials is the inverted U-gage, in which the two liquid levels in the two legs are the actual levels of the liquid measured, instead of being mercury or another special liquid placed in the U-tube itself. The main advantage is that there is no mercury to be blown over and lost.

An intermediate form of the glass U-tube type is the contact manometer, used for alarm purposes, or as part of automatic flow control systems, in addition to its use as a measuring instrument.

Replacing glass tubes by metal chambers, as a step in the complete industrialization of the U-tube gage, does not change its essential measuring function; but this alteration is never the only one; and the usual result is a thorough transformation into the many forms of devices commonly known as "flowmeter manometers"—which are, nevertheless, instruments for measuring *differential pressure*. Some of these modified U-gages are used for measuring flow-rate, liquid level, rotational speed, angular displacement and other variables.

Before closing the subject of U-tube gages, however, it is proper to repeat that the U-tube instrument is frequently used to measure one pressure (positive or negative), the other leg being open to the atmosphere. For applications where a draft or a small gage pressure (say, less than 0.5 psi.) is to be measured, some U-tube gages are designed with a float in the open leg. The float may actuate a pointer, a recording pen, or an electrical or pneumatic telemetering transmitter.

Multiple U-gages—By connecting a number of U-tubes in series, one obtains the equivalent of one U-gage of greater length than can be accommodated in an ordinary building. Mercury is generally used, with water in the top connections (successive bodies of air or gas would compress progressively and complicate readings, beside bringing in greater temperature corrections).

(b) *Single-tube Types*

Single-*tube* instruments are not single-column manometers or gages, but modifications of the two-column or U-gage in which, for the sake of convenience, one leg is a large reservoir—also called a chamber, cistern or well—and the other leg is a comparatively narrow-bore tube which is graduated. The graduations appear on a scale next to the tube. The scale is generally adjustable up and down, to facilitate zero setting. In instruments filled with liquids other than water, the scale may be compensated for specific gravity as well as chamber displacement, to read inches of water or other units. Square-root scales are provided when the instruments are to measure differentials across the primary elements of flowmeters. There are three advantages: (1) The scales are more open: with a cistern having an area 250 times that of the tube bore, an ordinary inch scale will give direct readings with a negligible error without being reset. (2) Only one scale to read. (3) The reading tube may be inclined to enhance sensitivity.

The single-glass-tube class may be divided into two main types—vertical tubes and inclined tubes.

Vertical tube comprises three subtypes: (*a*) manometers, (*b*) mercurial vacuum gages and (*c*) absolute pressure gages:

Mercurial vacuum gages of the open-cistern type can be used for close work, as in tests. Some have verniers, reading to 0.001 in., and by using them together with the corresponding barometers, corrections cancel out.

In the *absolute pressure gage*, the upper end of the glass tube is closed. As the tube was exhausted at the factory, the mercury rises in the tube when atmospheric pressure acts on the reservoir. Absolute pressure can be read directly on the scale.

The principle of the *inclined-tube gage* is simple, as shown in Fig. 5. If the tube in which the liquid rises is inclined, the liquid moves a greater distance in the tube for the same pressure change. The inclination of the tube shown in Fig. 5 is adjustable.

(c) *Micromanometers*

There are two distinct classes of micromanometers: (1) differential-liquid gages; (2) single-liquid gages equipped with verniers, microscopes, cathetometers and other precision optics—or with inductive, capacitive, electronic, magnetic and other precision pickups.

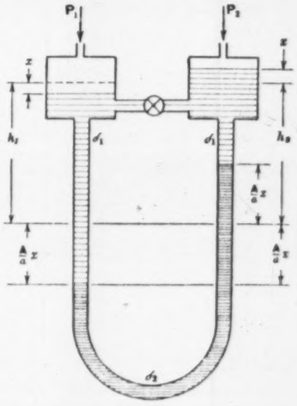


Fig. 6.

Fig. 6 shows one type of differential-liquid micromanometer. The liquids must, of course, be immiscible as well as of different colors because their interfaces must be sharp. See Section 6 of Part 1 for properties of manometric fluids (from which the reader can compute the multiplication factor) and for coloring agents.

Of ready-to-use commercial models, mention may be made of a form in which one leg of the U is large and serves as the reservoir; the other leg is of two diameters—medium at the bottom and fine at the top. Mercury falls a short distance in the reservoir, rises a greater distance in the medium section and drives oil a still greater distance up the fine bore.

Single-liquid MICROMANOMETERS of various forms, most of them originally designed in large scientific institutions, are commercially available. Their sensitivity is better than 0.0001 inch of water or other liquid.

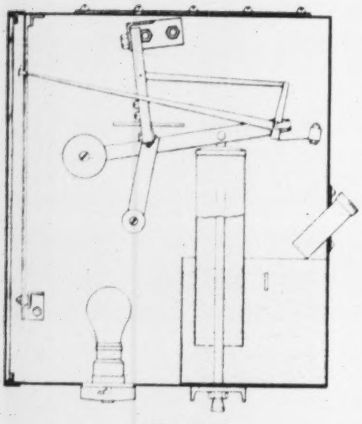


Fig. 7.

(d) Combination Piston and Liquid

This type is a liquid-column-loaded piston gage, akin to those in the next Section that are loaded gravitationally (with dead weights, scale beams and weights, and pendulums), but no kin to the above-described liquid columns nor to the spring-loaded piston gages. This is a true gravitational instrument. There is no appreciable "diaphragm effect." The maximum travel of the differential plunger is 0.02 inch. The pressure acting under the plunger is balanced (within a limit of error comparable to that of other gravitational instruments) by the head of mercury over the area of the large diameter plus a constant value due to the weights of the moving parts. Theoretically this type is a "primary standard" which can be calibrated by itself. It comes in ranges up to 25,000 psi., (minimum reading from 2 to 4 percent of maximum), the diameter of the small plunger varying according to the maximum pressure.

2. GRAVITATIONAL—WEIGHTS

(a) Weight-loaded Piston.

Piston gages are divided into weight-loaded and spring-loaded. The latter come under elastic deformation. The former are divided according to the method of loading: dead weight, scale beam, and pendulum.

Dead weight gages. — Dead-weight testers, such as those described in Section 10 of Part 1, comprise a gage along with a pump and other testing features. Such gages can be used only for steady pressures. Their advantage is high accuracy.

Pendulum manometers.—As previously mentioned, the pendulum manometer is more of a gage than a tester. A piston in a manometer tube is subjected to the pressure to be measured. The piston is connected to a weighted pendulum so that piston motion causes the pendulum weight to be raised or lowered to a point where the reaction on the piston due to the pendulum's inclination exactly balances the action of the fluid pressure on the piston.

(b) Weight-loaded Diaphragm.

A diaphragm pressure-element is a thin flexible diaphragm of a material such as brass, bronze, leather, or neoprene. The force of the pressure against the area of the diaphragm causes a deflection of the diaphragm, which is resisted by weights on the diaphragm.

(c) Liquid-sealed Bell Types.

Most bell-type instruments are used for low pressures, positive or negative. Most are draft or gas gages. As shown in Fig. 7, the air pressure to be measured is impressed on the inside of the bell through a pipe, causing the bell either to rise or sink until an equilibrium condition is reached. The bell may be counterweighted or pendulum-loaded. Because of the relatively large area of the bell, the forces are larger than in many other types of gages so that large indicator pointers can be driven directly. Two bells connected to the ends of a balance beam are used for measurement of differential pressures.

3. ELASTIC DEFORMATION

(a) Properties of Springs and Diaphragms

Fatigue. — Most failures of metal parts are caused by the continued repetition of relatively low stresses. The term "fatigue" is used to describe such failure. However, there is a stress below which the metal will not fail no matter how often the stress is applied. This stress is the "endurance limit." As long as the stress applied is below the endurance limit, the metal will not fail. It can even be strengthened.

The endurance limits for steels are roughly proportional to the tensile strength. However, a softer tougher steel often is better than a superhard steel.

Elasticity.—Elasticity is the tendency of a body to recover from distortion. The usefulness of springs and diaphragms depends on their elasticity. Any change of shape or volume of a body is called *strain.* Strain is the result of *stress,* which is the external applied force per unit area. Within the limit of elasticity, *stress is proportional to strain.* This is Hookes's law. The measure, or *modulus,* of elasticity is the ratio of the stress to the accompanying strain.

Drift, hysteresis, and dynamic ductility.—Elastic bodies do not recover perfectly from distortion because of drift, hysteresis and dynamic ductility. Drift, or creep, is the increase in the deflection of an elastic body when kept under constant load.

When an elastic body is subjected to a cyclic type of stress, the deformation in one direction is not exactly like that in the other direction. For example, when a spring is extended by a 2-lb. weight and then by a second added 2-lb. weight, it is found that when the second 2-lb. weight is *removed,* the spring extension is not the same as when the first 2-lb. weight was used. This phenomenon is called hysteresis.

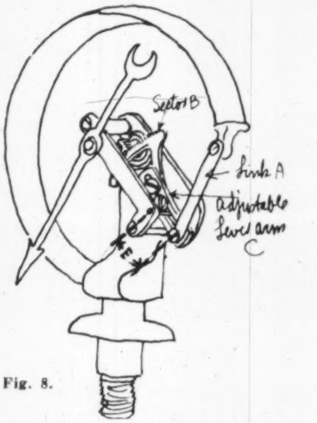


Fig. 8.

Ductility is the property of a metal to be drawn out into a thin wire. When a spring is operating in a cyclic manner it changes shape and characteristics over the cycle because of dynamic ductility and *damping capacity.*

(b) Spring-loaded Pistons

Best-known example of this large class is the engine "indicator" (which is a recorder). It has reached a high state of development and is available in many types—some producing pressure-time records instead of the pressure-displacement "card"; some utilizing null methods and point-by-point cycles; some recording maximum pressures only; some recording mean pressure; etc. The old familiar pencil or stylus has been supplemented by other recording means and media, including the optical lever recording on moving film. Most spring-loaded piston instruments are self-contained and ready-to-use; most can be calibrated statically—which is not true of some other classes of pressure-transient recorders. Below its frequency limit and above its low-range limit, each instrument is a high-fidelity recorder.

(c) Bourdon and Other Spring-type Tubes

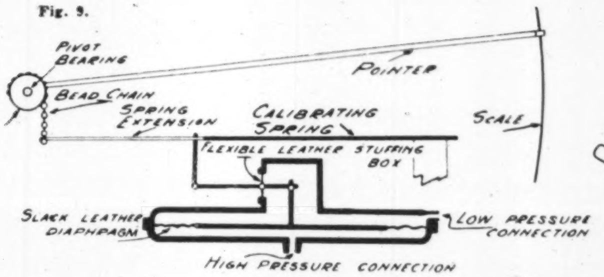
The tube-spring, or pressure-spring, gage is the most widely used. A typical indicating Bourdon gage is shown in Fig. 8. The pressure spring is a hollow curved tube of bronze (for use to 600 psi.), beryllium-copper (for use to 10,000 psi.), or alloy steel (for use to 10,000 psi. and above).

In addition to Bourdon tubes, pressure-spring gages use spiral and helix pressure tubes. Their mechanisms (toothed pinion as in Fig. 8, or other type) are usually provided with adjustments.

(d) Diaphragm, Bellows, Membrane and Capsular Types

Diaphragms are thin flexible plates—flat or corrugated. Their deflection can be opposed by the spring qualities of the diaphragm alone, or by a spring. As the diaphragm cannot be too large, the deflection of the center of the diaphragm cannot be large. Therefore, the mechanism usually provides a large multiplication factor (see Fig. 9). A corrugated diaphragm provides larger

Fig. 9.



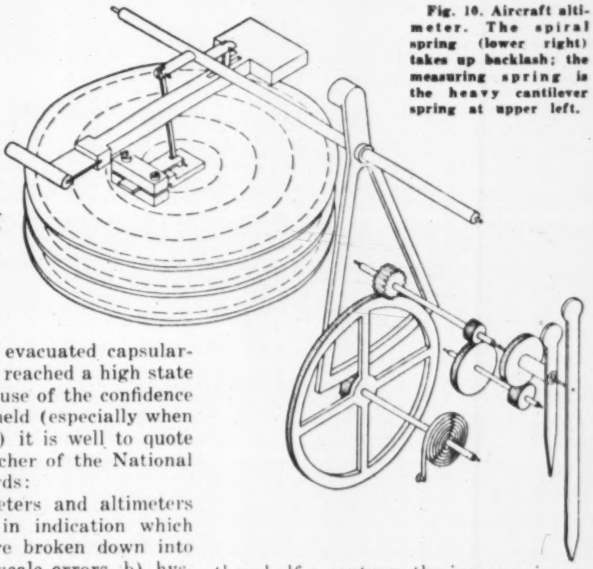


Fig. 10. Aircraft altimeter. The spiral spring (lower right) takes up backlash; the measuring spring is the heavy cantilever spring at upper left.

motion, but is more erratic in response. However, for low pressures below 10 psi., the diaphragm gage is generally considered to be superior to the Bourdon form. Greater care is required in calibrating diaphragm gages than Bourdon gages.

Bellows gages are used commonly for pressures or vacuums from a few inches of water to 100 psi. They are made in a variety of forms. The pressure generally is applied to one side of the bellows, and a spring is used on the other to oppose the motion of the bellows. The pressure range of the gage is determined by the effective area of the bellows and the spring gradient. Bellows are usually made of phosphor bronze or brass.

A pair of matched bellows (equal-area, etc.) is used in various designs for measuring (1) absolute pressure or (2) differentials; one advantage being that the link is in the open atmosphere, so that its motion can be transmitted to a pen-arm or other member without need of a stuffing box or other through-wall coupling.

Spring-loaded membranes.—A membrane is a SLACK diaphragm, which absorbs no energy (theoretically) and transmits the force of the draft or pressure to a calibrated member that measures the force by the deflection. Diaphragm gages are made for pressures up to 300 psig. and above. They are used also in draft gages. Phosphor-bronze cantilever springs are used in many slack-membrane gages.

Capsular-spring gages.—In this class of pressure instruments there are two sub-classes: (1) the instruments depending on the deflection of a capsular spring, double-diaphragm, etc., without external spring; and (2) those embodying a flexible box or capsule, whose motion is restrained by a separate carefully calibrated spring.

Another division of this class is into (1) instruments embodying an EVACUATED thin-walled vessel; (2) those in which the measured pressure is applied INSIDE the capsule; and (3) those of similar general design but capable of measuring DIFFERENTIALS across flow-meter primary elements, so that atmospheric pressure acts neither inside the capsule nor directly on its exterior.

Fig. 10 shows an aneroid box instrument with restraining spring—that is to say a barometer—though the particular instrument shown is an aircraft altimeter.

Aneroid barometers and altimeters, best-known of the evacuated capsular-spring gages, have reached a high state of perfection. Because of the confidence in which they are held (especially when of "famous make") it is well to quote Dr. W. G. Brombacher of the National Bureau of Standards:

"Aneroid barometers and altimeters may have errors in indication which for convenience are broken down into the following: a) scale errors, b) hysteresis, c) drift, d) zero shift, e) temperature errors, f) position error, g) friction effects, h) vibration effects, and i) dynamic performance."

If the instrument is a high-grade one in good condition, none of these is serious except the last, which pilots usually call "lag" and which is a source of danger because it may suddenly become worse by reason of one of the preceding causes of error. In the early years of commercial aviation, some crashes in foggy weather were caused by poor dynamic performance of altimeters.

4. Electrical

One must distinguish between electrical *methods* of measuring pressure and "electrical" pickups or transmitters. The true electrical methods are those which utilize an electrical effect of *pressure*, that is to say, of force per area—NOT OF FORCE, NOR OF MEASURING-MEMBER DEFLECTION.* They were listed under "Classifications" (in Section 4 of Part 1). They may be classified also as:

(1) The change in some electrical property of a solid conductor or semi-conductor subjected to external pressure;

(2) The change in some electrical property of a fluid—a gas or a liquid—as its own pressure varies.

Theoretically, one could use a number of electrostatic and electromagnetic effects of pressure, each multiplied by the number of available elements, alloys and mixtures. Practically, only a few effects are utilizable in commercially-available instruments:

(a) Resistance or Conductance of Solids and Liquids

Two distinct types of primary elements of instruments deserve mention as fully industrialized:

1. Special-alloy Wires.—For more than half a century, the increase in resistance of various kinds of wires (or of mercury in non-conducting tubes) has been used in laboratories to measure high pressures, each scientist solving his own installation problems. Since about 1949 there have been available easily-installed "cells" in which manganin coils are sealed and isolated by a flexible thimble filled with non-conducting fluid. The outside diameter is about 4 inches and a typical length is about 16 inches. Calibrated "cells" are available in ranges from 0-30,000 psi. to 0-200,000 psi. Sensitivity is reported as "within 25 psi. in 100,000 psi." Since about 1952, calibrated "cells" using gold-chromium alloy wires have been available in ranges to 150,000 psi.

The pressure coefficient of this alloy is about half that of manganin but its temperature coefficient is one-fifth to one-fortieth that of manganin.

2. Carbon, etc.—This type comprises two sub-types: (1) Various forms of slack-wall bulbs, capsules or chambers filled with a weakly-compacted mass of tiny spheres or granules of carbon, graphite, etc. In this sub-type, the volume resistivity of the granular air-and-solid primary element decreases with increasing pressure and consequent increases in number of contacting surfaces and in total contact area; the flexible wall or diaphragm serves only as a seal and plays no part in measuring pressure. (2) Various forms of stacks or piles of disks or of rectangular plates, compressed axially by external pressure on a fluid-sealing slack diaphragm which plays no part in measuring pressure. This sub-type, too, is a truly electrical pressure-measuring instrument because the elastic stack itself is the calibrated "spring." Both these sub-types are successfully used for measuring rapidly-fluctuating pressures. (Devices in which the stack merely converts into an electrical change the deflection of a calibrated spring belong to the Elastic Deformation class: they do not use an electrical method of pressure measurement.)

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*All these methods could be called *piezoelectric* but this particular combination of two Greek roots was reserved by the brothers Curie in 1881 for one category only.

(b) Conductivity of Fluids.

The electrical conductivity of a gas depends on the number of ions per unit volume and thus provides a truly electrical (or electro-ionic) method of pressure measurement. Since this method is useful only at low pressures, the instruments are vacuum gages (described in Part 3). The electrical conductivity of some electrolytic solutions (e.g. copper sulphate) varies with pressure. The effect is practically instantaneous—an advantage—but polarization and temperature errors limit the usefulness of this method; and no widely-applicable pickup has yet made its appearance on the market.

(c) Luminous Discharge

Another type using a truly electrical (specifically electro-ionic or electronic) method of pressure measurement is the glow-discharge vacuum gage (Part 3).

(d) Piezoelectricity

Several natural and synthetic crystals with asymmetrical structures, when sandwiched between electrodes, produce a potential difference across the plates when dimensionally changed by a mechanical force. This potential difference is proportional to the deformation, which (up to the elastic limit) is exactly proportional to the force. Therefore, piezoelectric crystals make ideal "fatigueless springs," but only when maintained at constant temperature and (for most materials) only when protected from moisture, chemicals, fumes, etc. Because of leakage of charge, it is extremely difficult to use piezo units for *measuring* steady pressures or slowly-varying pressures.

Piezoelectric crystal units are manufactured in many hundreds of sizes and shapes. Most units consist of two or more slabs, with the electrodes connected in series or in parallel. The great majority are purposely designed to be *unidirectional* so that squeezing at a right angle to the sensitive axis will produce no voltage change. The most obvious way of using such piezoelectric crystal assemblies for pressure measurement is in rigid chambers with one end consisting of a fluid-sealing diaphragm that merely transmits the pressure without playing a part in its measurement. For omni-directional (also called non-directional) *response*, the preferred material is tourmaline, which is volumetrically or hydrostatically sensitive. Or else, a stack is used in which the expansions and contractions in the lengths, the breadths and the thicknesses of the individual crystal slabs do not cancel out. Such a stack (known as a "volume expander"), in a rubber housing with oil filling, is widely used in under-water applications where sensitivity to relatively small pressure changes must be accompanied by ability to withstand the pressure of shocks from explosions. In various other pickups the pressure-measuring "springs" are "bender" and "twister" forms of crystal pairs.

All such pickups are true electrical pressure-measuring elements rather than electrical transmitters of measurements performed by elastic diaphragms.

Piezoelectric pickups are used successfully to measure low absolute pressures in vacuum applications (the low limit receding year by year with refined oscillating-plate techniques); and also to measure high pressures in some ordnance applications (highest pressures undisclosed). The voltage outputs of the pickups range from millivolts to thousands of volts; the circuits have grown in number and variety; as have also the electrical and electronic indicators, recorders and controllers and their accessories such as amplifiers. The "classical" method of measuring d-c. voltage (good only for one rapid increase of pressure) has given way to a-c. techniques, such as oscillography and measuring frequency changes caused by pressure changes. This latter method is becoming widely used because frequency changes can be measured to an accuracy of one part in tens of millions.

(e) Magnetostrictive

Rods made of some ferromagnetic metals and alloys exhibit dimensional changes when subjected to longitudinal magnetic fields. The response being extremely rapid (microseconds), most commercial units are used as vibration generators. The converse effect (influencing a magnetic field when the bar is stretched or compressed) is used for pressure measurement somewhat as the converse piezoelectric effect is used, but with the important difference that a magnetostriction load-measuring "spring" must comprise not only the rod but the associated magnetic structure. Hence the relatively small number of assemblies designed for measuring pressure. Their principal advantage is high fidelity in recording pressure fluctuations.

(f) Electrokinetic

The electrokinetic method is the newest purely electrical method of measuring pressure although the utilized effect (the streaming-potential phenomenon") was discovered in 1859. This effect is similar to piezoelectricity and magnetostriction in that a change of pressure produces an electrical change; but it differs in that it involves the minute FLOW of a polar liquid into and out of the opposite faces of a porous-material partition. (Hence the name: for kinetic means motional.) The preferred orientation of polar molecules at the two interfaces results in a potential difference which is a function of the pressure difference and whose sign changes with the direction of the pressure difference. Thus, the electrokinetic method cannot be used for the measurement of steady pressures. It is finding applications for recording pressure fluctuations. The upper and lower frequency limits are set by the geometry and size (and consequent inertial constants) of each pressure pickup.

5. ELECTRICAL TRANSMISSION

The great majority of pressure measuring systems called "electrical" are systems in which the pressure measurement is performed mechanically (by a gravitational means such as a liquid column, by an elastic member, etc.) and in which an electrical device converts a change of level or of deflection into a change of current or voltage or frequency for convenient transmission over wires or by radio. The numerous types and varieties fall into mutually-exclusive classes somewhat like the methods described in the preceding Parts. Most of the electrical transmitters are electrical kinetic prime relays or "electrical micrometers" of the resistive, capacitive or inductive types. Their *general* characteristics are dealt with in Part 5 of Ch. I of the 1951 edition of this book; the following pertains to their *pressure* uses.

(a) Resistive

Electrically, resistance-type transmitters can be classified simply into: (1) variable resistance; (2) resistance-ratio. But see "III" below.

Structurally, resistance-type transmitters can be conveniently classified according to the pressure-measuring devices with which they are associated: (1) Mercury-column devices, (2) Elastic-deformation devices. Of their comparative characteristics, the principal ones are as follows:

	Suitable for dynamic meas'm'ts	*Operation is frictionless*
Mercury	No	Yes
Elastic	Yes	No

(1) For mercury levels the two principal forms of resistance-type transmitters are:

(i) Axial wires. These are almost always platinum, of uniform diameter, etc., with output exactly proportional to level; but some "shaped" resistors are also available. For single columns the simplest arrangement is one variable-resistance wire as in Fig. 11A. For differential pressure measured by a U-tube manometer, the bridge-arm arrangement shown in Fig. 11B has obvious advantages in minimizing errors and improving sensitivity.

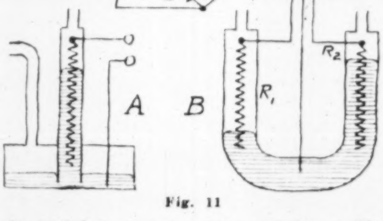


Fig. 11

(ii) Multiple contact arrangements. These are not continuously-variable but step-variable. They are employed in well-known industrial manometers in which the number of steps is large enough to assure the required sensitivity and accuracy. One advantage is the possibility of exact "shaping," as in **Fig.** 12 which shows an arrangement whereby the electrical output is the square root of the differential pressure.

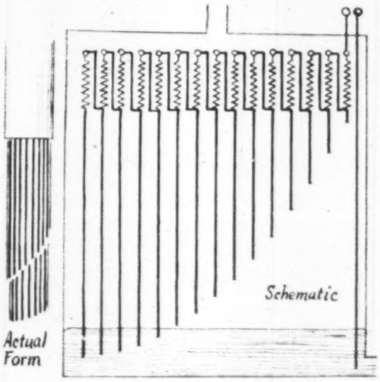


Fig. 12

(2) For elastic-deformation pressure-measuring devices, resistance-type transmitters are available in hundreds of forms and may be classified in many ways. The following set of five classifications was made up especially for this chapter on *pressure*:

I

1. Actuated by force, with little displacement; 2. Actuated by displacement, with friction minimized in various ways.

II

1. Continuously-variable; 2. Step-by-step. Note: wiping a wire-wound resistor is considered a continuous action.

III

1. Simple rheostat; 2. One resistor connected as a voltage divider ("pot"); 3. Two separate resistors, usually for bridge-arm function; 4. Full bridge arrangement with all four arms active.

IV

1. Can only measure steady or slowly-varying pressures; 2. Suitable for recording fluctuations and transients.

V

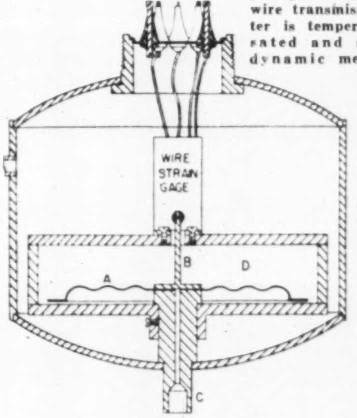
1. Liquid resistors; 2. Granular materials; 3. Solid resistors, subdivided into wires, coatings, etc.

The author urges readers to refer to these classifications when about to make decisions. Here is why: Up to about 1946 or '48 most resistive transmitters were attached to previously-designed Bourdon-tube gages, bellows gages, etc. Now there are many *ready-to-use* resistive pickups which look much alike on the outside but which vary enormously in zero stability, ambient-temperature range, resistance to mechanical shocks on housing and to overpressures on deflecting member, etc. Since these pickups vary enormously in price, the study of classifications will not be a loss of time.

At present, two forms of resistive pickups probably outnumber all others (and probably will for several years to come). Both belong to II-1, IV-2 and V-3. They are the resistor-wiping type (commonly called "potentiometer") and the "strain gage" type.

Resistor-wiping pickups were inexpensive and rather unreliable up to recent years. Now aircraft and missile applications call for light weight, small size and hermetic sealing, in addition to accuracy. Friction has been minimized but it remains a limitation where small-area diaphragms must be used.

Most strain-gage-type pressure pickups use strain-sensitive wires, but a trend toward the use of strain-sensitive resistive coatings seems to be growin. The numerous varieties of wire-resistance pickups divide themselves into two mutually-exclusive categories: (1) Bonded-wire, (2) Unbonded-wire.



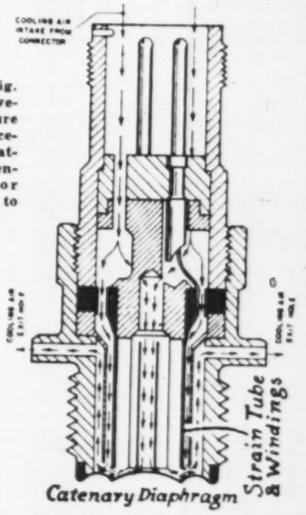


Fig. 13A (left) and Fig. 13B (right) show, respectively, low and high-pressure pickups utilizing resistance-wire transmissions. The latter is temperature compensated and suitable for dynamic measurements to 20,000 cps.

Bonded-wire strain gages had proved useful before World War II in the testing of materials, of parts and of structures; and they were adapted to measuring the deformation of elastic members—particularly of the small elastic members used in studying rapid fluctuations and single transients. Their most obvious advantages* stem from their "postage-stamp" method of application to optimal locations on curved as well as flat surfaces, on opposite sides of bending members, etc.; and from their small size which enables them to transmit deformations of thousandths of an inch. Temperature errors are low nowadays, since the introduction of various copper-nickel alloys. Moisture, of course, ruins unsealed assemblies. Electrical output is usually linear because the pressure-measuring members themselves must not be stressed beyond their own elastic limits; but in many cases the relatively low strains result in lower sensitivity than obtainable with the unbonded type and other electrical transmissions. Mention must be made, however, of the fact that there are on the market high-precision pickups known as "cells"—many times larger than the usual pickups—in the form of hollow cylinders which may be obtained with calibration certificates.

Unbonded-wire strain-gage-type pressure pickups are usually made up as four-arm bridges. A feature is INITIAL TENSION on all four wires during manufacture, so that there always is some residual tension on the pair that shortens while the other pair lengthens. Various mechanical arrangements multiply or reduce the deflection of the elastic member, as may be required. Multiplication is used with relatively small and rigid members, in order to yield high sensitivity. A trimmer resistor is usually incorporated during manufacture in order to make the bridge ratio at balance equal unity to three or four decimals. Assemblies are available for d-c. (dry-cell), a-c., or carrier-frequency excitation; for absolute and differential pressures; for vibration-resistance requirements, etc. High-precision types are the rule.

(b) Capacitive

Principal applications of the variable-capacitance principle to transmission of pressure measurements are (1) rapid fluctuations or transients, (2) high pressures—usually requiring stiff diaphragms and small deformations; and also (3) low pressures and extremely small pressure changes causing small displacements of large diaphragms—for all of which the parallel-plate capacitor type of "electrical micrometer" is suitable. Many capacitive-transmission pressure pickups on the market are of the "spark-plug" form for engine tests; and most of these have diaphragms integral with housings in order to prevent edge-creep as well as "jitters" and "ringing." Upper frequency limit is 15,000 to 20,000 cps., depending on the accuracy required. For the characteristics of capacitive transmissions in general see pages 51-53 of the 1951 edition of this book.

As a circuit element the capacitor may be used as one arm of an a-c. bridge, as a frequency-determining element in an oscillating circuit, or to amplitude-modulate the carrier produced by an oscillator. Resonant circuits are the favorites for industrial work because of the ready availability of the required instruments.

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*Reference is here made to ready-to-use pickups in which the bonded-wire units have already been applied to the surfaces of elastic members—an operation that looks simple but requires experience and skill if the assembly is to hold its calibration not merely for one tensile test in one direction but for months or years of upscale and downscale measurements.

(c) Inductive

All of the inductive-type transmitters associated with liquid-column and elastic-deformation pressure-measuring primary elements are kinetic or displacement transmitters.

Most of these transmit relatively large displacements; they are not electrical micrometers. Theoretically, inductance pickups can be designed for microinch deflections and there are examples in military and other applications; practically, the parallel-plate capacitor is much simpler and cheaper as a micrometer. Moreover, the inductive type is available in a rich variety of sizes and geometries, many of which have been found in practice to be better than capacitive or resistive transmitters for converting into electrical signals the relatively large displacements of bellows, Bourdon tubes, etc.

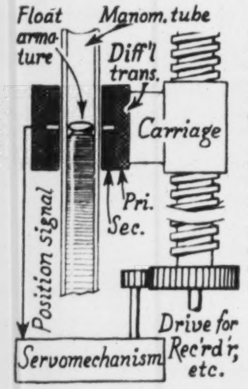

Fig. 14. Electrical transmission system of the inductance division, mutual-inductance class (III) and differential-transformer type (1), commanding a follow-up servo system. This application (to extremely small displacements) is unusual for inductance transmissions.

Oldest (before World War I) of the inductive transmitters are the inductance-ratio and inductance-bridge position telemetering systems. Today so many more types come under "position" or "displacement" that numerous schemes of classification are possible.

Much of the fundamental treatment of inductive prime relays in the 1951 edition (pages 50-52) applies equally to inductive pressure pickups. The classification is as follows:

I. VARIABLE INDUCTANCE

1. Solenoid; 2. Variable air gap

II. INDUCTANCE RATIO

1. Solenoid; 2. Variable air gap; 3. Shielding vane

III. MUTUAL INDUCTANCE

1. Differential transformer; 2. Variable-air-gap transformer; 3. Absorption type; 4. Coupling loop.

(d) Synchros

These usually operate by electromagnetic induction but they do not belong under *(c)* because their output is not an electrical signal. They are electrical transmitters of *angular position*, sold under various names such as Selsyn, Autosyn, Telegon, Synchrotel, Magnesyn, Inductosyn, etc. Most of these systems are too expensive for civilian use as transmitters of pressure-measuring-element deflection.

6. Pneumatic Transmission

Even more than in the case of electrical transmitters, the pneumatic transmitters associated with pressure-measuring elements are to be considered prime relays. Moreover, the thorough treatment of pneumatic prime relays in the first edition of this handbook (pages 38-45) applies to pressure (including differential) more than it applies to temperature and other measurables. Only two supplementary remarks need be made here:

1. When it comes to converting a pressure change into a change of air pressure, all the possible classifications can be dropped in favor of the one which consists of (1) non-balance types; (2) position-balance types; (3) force-balance types.

2. Although pneumatic transmission systems cannot compare in speed with electrical systems, they are sufficiently instantaneous for remote indication and remote recording over the distances of even the largest industrial plants. But when it comes to automatic control, they should not always be considered "instantaneous enough." Nor, of course, should they always be condemned as too slow. Only in recent years have elaborate studies been made of pneumatic-line lag (especially by Bradner, Iberall, Eckman, Gess, and Moise), ending guesswork once for all and ending excuses for blind acceptance or blind rejection. An extremely brief summary of the findings, put into simple words, is as follows:

(a) The volume of the bellows or other device at a remote receiver (and especially the volume of the diaphragm motor at a remote valve) is an important factor because a large volume requires a large *flow*, accompanied by greater frictional retardation.

(b) A sudden pressure change at the transmitter is attenuated and arrives as a gradual change, theoretically and practically like the temperature at the far end of the copper bar whose near end is suddenly heated, in the familiar Fourier heat-conduction experiment.

(c) Theoretically, a "small" part of the sudden change should travel at the speed of sound regardless of tubing inside diameter; 63 percent of the sudden change should *usually* travel in the *usual* industrial tubings at *about* half the speed of sound (details are omitted here).

(d) A set of rough figures that can be memorized is that, in the "average" industrial installation, "nearly" the full extent of the sudden change (say 95%) travels at about one-fortieth of sonic speed—about 25 feet per second—in "small" (less than 0.2-in. I.D.) tubing; and at about 50 fps. in "medium" (0.3-in. I.D.) tubing. By "average" installation is meant one ending in an elastic device with a volume of 20 to 60 cubic inches—not with a volume of hundreds of cubic inches.

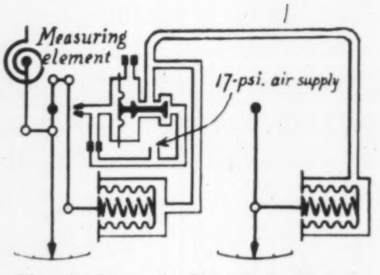

Fig. 15. Pneumatic Transmission System.

7. Optical

Optical methods of pressure *measurement* still belong in laboratories (where they often are called *density*-measurement methods); and may be disposed of by stating that they are of great value in supersonic wind-tunnel work, etc., where they make possible the fastest known recording of shock waves and other extremely rapid local pressure changes *without disturbing the particular volumes under study* as do all ordinary pressure pickups.

Optical *transmission* of pressure-measuring-element displacement, on the other hand, is entirely practical. The available devices divide themselves into two broad classes: (1) photographic recording of liquid column height or elastic-element deformation—usually by a shadow-casting method; (2) photoelectric devices for remote indication and recording. As a rule, the mirrors, vanes, etc., impose negligible loads on the pressure-measuring elements. And when the mirror is simply a polished part of the surface of a deflecting element, there is no increase whatever on the inertia of the system.

PART 3—VACUUM INSTRUMENTATION

1. General

Many of the previously-described methods are used for measuring "ordinary" vacuum: negative pressure with atmospheric pressure as the reference value—usually expressed as "inches of vacuum." This Part deals with methods of measuring "low" and "extremely low" absolute pressures, the zero point being a perfect vacuum. This zero is inaccessible: the best man-made vacuum contains millions of gas molecules per cubic centimeter. The scientific unit of absolute pressure is one dyne per square centimeter, also called the microbar because it is one-millionth of the bar (750 mm. of mercury column). The generally-used unit of absolute pressure is the micron: one-millionth of one meter (or 0.001 mm.) of mercury column. A "low" absolute pressure is any less than 1 mm. of mercury; an "extremely low" absolute pressure—also called a "high" vacuum—is a pressure less than a millimicron (10^{-3} micron). The majority of applications in the vacuum industries call for measuring pressures between 10^{-3} and 10^3 microns. No single method of measurement is entirely satisfactory throughout this millionfold range. The following abridged treatment does not deal with all known methods; but the methods discussed are collectively applicable throughout this range and even beyond.

2. ELASTIC-MEMBER GAGES

Because of their simplicity and convenience, and in spite of their fragility, various thin-wall Bourdon-tube, spiral, helical, capsular and bellows gages are being used for measuring absolute pressures in the "low vacuum" ranges. The more sensitive ones are not mass-produced but are made by skilled glass-blowers. The glass (or fused quartz) must be one whose elastic properties remain satisfactorily constant after artificial aging, so that a direct-reading gage will hold calibration if not abused. Elastic-member gages are generally used with a KNOWN vacuum on one side, as the reference —just as atmospheric pressure is the zero of an ordinary Bourdon gage. In some instruments it is possible to utilize a contactless electrical-micrometer means of telemetering.

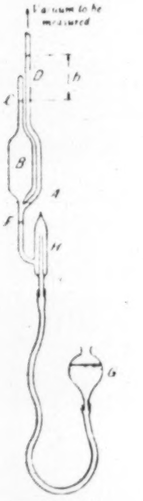

Fig. 16

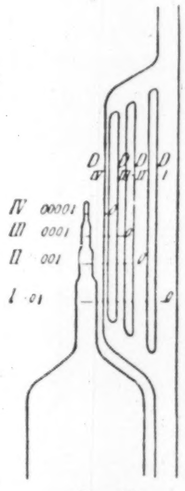

Fig. 17

3. COMPRESSION MANOMETERS

The special type of compression manometer used in vacuum work has been known since about 1880 as the McLeod gage. It is a primary instrument (see Part I). Therefore, a set of two to five McLeod gages covering ranges from about 0.01 micron to about 50 millimeters is customarily used in many plants for calibrating the other vacuum instruments.

Fig. 16 is a schematic diagram of the classical form of the McLeod gage. It consists of a bulb B with a narrow tube C at the top, and joined at A to the vacuum apparatus when the mercury level is at F. The volume V (volume of bulb plus that of C) is cut off when the mercury reaches A. The volume v is that between the top of C and a graduation on the tube. When the mercury is raised until its level reaches this graduation in C, it will rise to a higher level in D. The difference of level h is a measure of the pressure of the compressed gas if the initial pressure was small compared with h—that is, if the ratio V/v is large enough. This approximation is valid, since the ratio V/v can be made 100 or 1000 more. The pressure h will then be made 100 (or more) times greater than the initial pressure of the gas that was cut off and compressed.

For raising and lowering the mercury, the simple arrangement shown in Fig. 16 is commonly employed. Reservoir G is joined to the gage by a flexible rubber tube; and either the reservoir or the gage is raised or lowered. In permanently-installed gages, this operation is made semi-automatic, with mechanical or compressed-air or vacuum auxiliary power.

If the compression chamber has the same diameter throughout, the range of the gage is limited. This limitation is eliminated by making the compression chamber into a series of capillaries of decreasing diameter, as shown in Fig. 17. The sizes are so arranged that the marks will be far enough from the joints, so that the diameters at the marks will not be affected when the joints are made. The greater length of the widest tube will enable the gage to reach the usual lower limit. With this arrangement alone, the surface tension corrections would be different for the different marks. This is avoided by Dunoyer's invention which consists of a number of tubes of corresponding diameters parallel to the compression chamber, as shown in Fig. 17. Each tube of this set has a mark level with the mark in its corresponding portion of the compression chamber. There is thus no need to apply any surface tension correction, and readings are made directly.

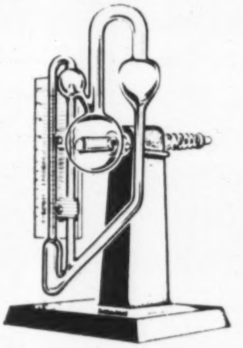

Fig. 18

McLeod gages cannot be used where condensable vapors are present. Their PRECISION is limited by capillarity and other effects, as well as by readability (two levels must be observed). Their ACCURACY is ordinarily 2 percent of the value of the absolute pressure (1 percent or better in highly-developed models). This is the INTRINSIC accuracy of a well-made gage with recently-cleaned capillaries; such accuracy is seldom if ever attained by persons not trained in vacuum techniques.

The principal inconvenience in the use of the McLeod gage is that its operating liquid is mercury, whose vapor pressure at room temperature is about two microns (hundreds—or thousands—of times greater than the pressures to be measured in high-vacuum applications) compelling the installation of mercury-vapor traps using liquid air, etc.

It was pointed out in 1915 by Gaede (and generally overlooked until B. B. Dayton recently brought it up) that the flow of mercury molecules from a McLeod gage to a liquid-air trap—even if slow—makes the partial pressure of air in the manifold higher than the pressure of air in the McLeod, the correction factor at room temperature being $1+0.13\,R$ where R is the radius (in centimeters) of the connection between trap and gage.

Among many forms and sizes of McLeod gages, mention may be made of:

(1) Large-bulb high-ratio instruments, requiring a large amount of mercury, in which mercury raising and lowering operations are mechanized.

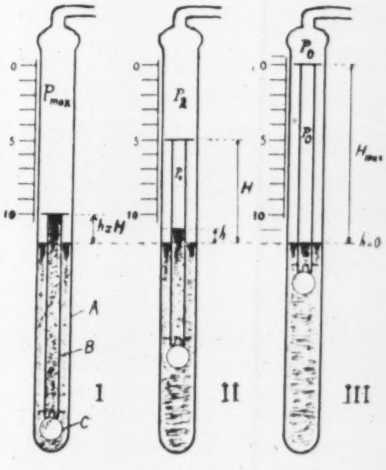

Fig. 19

(2) Small portable instruments in which these operations are performed by rotating the entire instrument, or its glassware part. See Fig. 18.

(3) Electrical remote-reading systems. These cannot be continuous-indicating because the compression manometer is an intermittent-sampling instrument. The sampling is performed automatically at regular intervals and each operating cycle ends with the transmission of the reading. Electrical means of transmitting liquid level have been described in a preceding Section; for industrialized McLeod gages the device is a platinum wire stretched axially in the capillary chamber.

The Dubrovin Gage, Fig. 19, consists of a glass tube A, partly filled with mercury, in which floats tube B buoyed up by hollow glass sphere C. Tube B having been evacuated, its upper part contains such a small quantity of air and mercury vapor that it is compressed to a negligibly small volume (diagram I) when the measured absolute pressure is range-maximum or greater. The float rises to its maximal height when the instrument is connected to a nearly-perfect vacuum (III). In between (II), the calibration depends on the constants of each individual instrument. The usual range is 0 to 20 mm. of mercury.

4. LOW-PRESSURE GAS PHENOMENA

At a pressure of one micron, most gases have a mean free path of the order of INCHES. For example, each individual molecule of hydrogen at 1 micron and 25 C. travels 9.31 cm. (3.68 in.) between collisions with other hydrogen molecules. For helium the mean free path is 14.7 cm.; for oxygen, 5.40, for nitrogen, 4.99. Therefore, within the measuring chambers of high-vacuum gages, molecules travel as individual particles and collide only with the surfaces of the instruments—not with one another. Some of the physical properties of gases at these low pressures become simple and their relations to pressure can be expressed by simple equations which permit (theoretically) the design of primary instruments. Some of these properties are utilized in the instruments dealt with in the following Sections. Most of the commercial forms of these instruments, however, have to be calibrated initially (and periodically) because of limitations of geometry, inconstancy of thermal and thermionic properties, unpreventable absorption and adsorption, and numerous other factors which complicate the utilization of the simple effects.

Before discussing the measuring instruments, mention may be made of the "glow discharge gage," which is simply a glass tube in which a cathode and anode have been sealed. If high-voltage d.c. or interrupted d.c. is applied to these electrodes, the appearance of the discharge provides a semi-quantitative indication of pressure—a *usable* indication of "degree of vacuum."

5. VISCOSITY METHODS

(1) *"Laboratory"*

These deserve mention because they are used in some plants, for calibrations below the McLeod limit. One utilized effect is the damping capacity of the gas, which varies inversely with pressure. Extremely fine disks, plates, fibres, membranes, etc., are set in motion (in some instruments by an external magnet attracting a speck of iron embedded in the moving member); then the dying-down of the oscillations is observed. Knowing the dimensions and the elastic and other coefficients, the pressure is computed from the observed periods. Each reading is a time-consuming experiment. Most instruments must be set up carefully on vibrationless benches. They include types known as molecular gages, torsion gages, disk gages, decrement gages, and by the names of their inventors: Langmuir, Dushman, Bruche, Sutherland, Haber, and others.

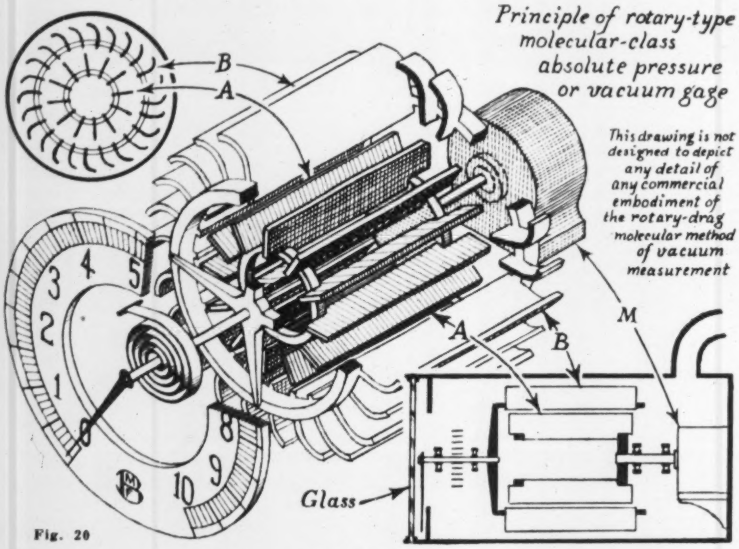
Principle of rotary-type molecular-class absolute pressure or vacuum gage
This drawing is not designed to depict any detail of any commercial embodiment of the rotary-drag molecular method of vacuum measurement
B
A
M
A
B
Glass
0
1
2
3
4
5
8
9
10

Fig. 20

(2) *"Military"*

Brief mention is here made of the fact that some viscosity or molecular gages have been ruggedized and automatized, with the oscillating member set into motion at regular intervals, its decrement measured, and the successive reading telemetered over wires or by radio. The instrumentation is necessarily elaborate and extremely costly.

(3) *"Industrial"*

Of the numerous attempts made in Europe and in the U. S. to design a rugged quick-reading embodiment of the viscosity method, two approaches appear to promise future industrial usefulness:

The first is the use of edge-clamped piezoelectric crystal wafers as oscillating members, with automatic reading of decrements. At this writing (summer 1954) the systems still seem to belong to the expensive "military" category, but the costs will come down when commercialization dictates the use of inexpensive non-critical components.

The second approach—even more promising and already available—is sketched in Fig. 20. A miniature synchronous motor drives inner member A so that the deflection of spring-restrained member B depends on (1) the motor speed—which in the first commercial model is exactly 3600 rpm., the a-c. line frequency; (2) the spacing and other geometric factors; (3) the stiffness of the spring; (4) the number of gas molecules between A and B, i.e. the absolute pressure; and (5) the specific gravity of the gas or gas mixture. The actual relation between absolute pressure and pointer deflection for any gas probably defies mathematical prediction but the curves (Fig. 21) show the effect of friction on deflecting member B and their shape seems to suggest the probability that the first model will be followed by others in which this friction will be not only reduced but completely eliminated.

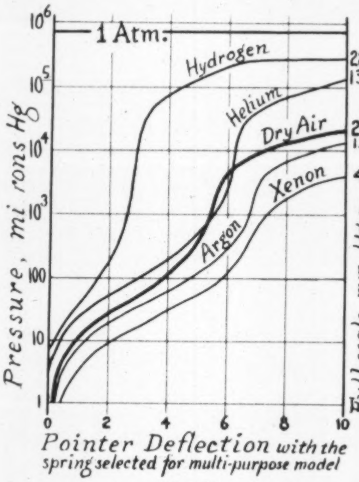

Fig. 21

6. RADIOMETER GAGES

These are commonly called Knudsen gages, after the designer of the first successful one. The utilized effect is that a mechanical force is produced between two surfaces, one heated and the other at the temperature of the gas, by the molecules rebounding from the hotter surface with more kinetic energy than those striking the cold surface. This force is independent of molecular weight, is proportional to $T_1/(T_2 - T_1)$ and is proportional to the number of molecules, hence to the absolute pressure. Temperature measurement difficulties make most radiometer gages unsuitable for plant use. Among modern designs is one which uses a modified principle: constant wattage input to the heater. It is particularly useful because each wattage setting gives a different scale.

7. CONDUCTIVITY METHODS

This method utilizes the exactly linear relation between the thermal conductivity of a gas and its pressure when all molecules travel between a heated surface and the surrounding surfaces, without exchanging energy among themselves. This method is embodied in the *hot-wire* gages, which are divided into four distinct classes:

(1) *Pyrometric* or *Thermocouple Gages.*—In the numerous types of this class, a constant current heats a filament or ribbon, whose temperature is measured by a thermocouple whose

measuring junction is welded to the heated element. The walls of the measuring chamber are thermostated in some of the more refined instruments. Each instrument requires individual calibration because the heated-element temperature depends not only on pressure but on radiation, on end-conduction, and on other effects, thus yielding a non-uniform scale law in each case.

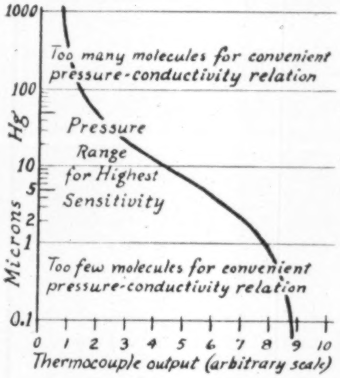

Fig. 22. The characteristic curve of one fairly typical hot-wire gage, showing its region of maximal sensitivity.

(2) *Resistance* or *Pirani* or *Pirani-Hale Gages.*—In these gages the utilized effect is the change in resistance of the heated element with a change in gas conductivity, hence in absolute pressure. Electrically, two different principles are used: (a) constant voltage; (b) constant current. In most commercially-available instruments the circuit is a Wheatstone bridge and there are two duplicate bulbs, one with a tubulation for attachment to the vacuum system and the other a permanently-sealed reference—usually evacuated to the highest vacuum which the user will want to compare.

(3) *"Thermistor" Gages.*—These differ from the Pirani-Hale gages in that the heated elements in the sampling bulb and in the reference bulb are nearly-identical units both made of a semiconducting material. Such materials differ from metals and alloys in that their temperature coefficients of resistivity are (a) greater, (b) nonlinear and (c) negative. The advantage is higher sensitivity—not higher accuracy in the present state of the art.

(4) *Linear-expansion Gages.*—In these gages the temperature of the heated element is measured by measuring its length. Numerous mechanical designs are in use, including contact arrangements for automatic control.

8. IONIZATION METHODS

As the name implies, the utilized effect is that in a triode the number of gas molecules ionized by the electrons emitted from the cathode varies with the pressure when the accelerating voltage is maintained constant (and when the electron current itself is 10 ma. or less). The number of positive ions striking the collector electrode per unit of time—i.e. the plate current—is proportional to the pressure in the high-vacuum ranges, but the scale laws become nonlinear curves for ranges that exceed about one micron. In the last twenty years, advances in electronics have been accompanied by improvements in ionization gages. Today these gages are available in many types and varieties all of which, however, may be divided into three groups: (1) thermionic gages, (2) Philips gages, and (3) "Alphatron" gages.

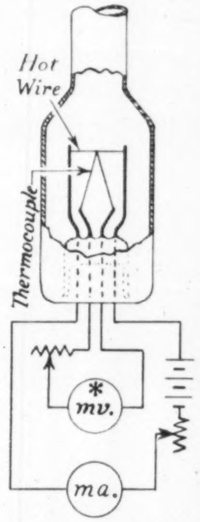

Fig. 23. Thermocouple type of vacuum gage, and circuit.

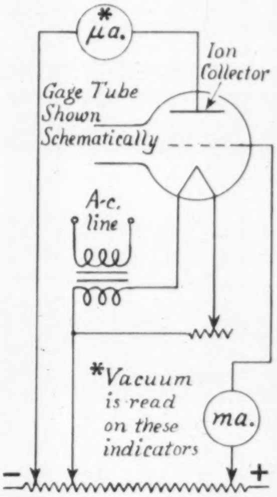
*
μa.
Ion Collector
Gage Tube Shown Schematically
A-c. line
*Vacuum is read on these indicators
ma.
−
+
−25v. 0
+150v.

Fig. 24. Conventional ionization vacuum gage (with tube like a triode), and circuit.

(1) *Thermionic.*—These follow conventional electronic circuit and electron-tube design except for (a) various function-improving geometrical designs; (b) various cathode materials to avoid burn-out when the vacuum is broken while the cathode is still hot; (c) bridge circuits. In thermionic gages, cathode temperature regulation is critically important because emission varies exponentially with temperature. As a rule, power supplies must be of the highest quality.

All ion-gage tubes but one are like radio triodes structurally; the exception is the "inverted" design (Fig. 25) by R. T. Bayard and D. Alpert. Their aim was to minimize a source of error which had been unsuspected, namely the residual current due to soft x-rays. These x-rays, created at the grid of the conventional tube by thermionic electrons from the central filament, release photoelectrons from the surrounding ion collector plate. Because of this false current, the higher the measured vacuum, the greater the error; and ion gages were considered unreliable below 0.0001 micron. Today, conventional ion gages can be used down to 10^{-6} micron, but only in the hands of a skilled user who allows for this effect and other error sources. In the new "inverted" design, however, the filamentary ion collector offers such a small target to radiation from the grid that the gage can be used with assurance to measure pressures as low as 10^{-7} micron.

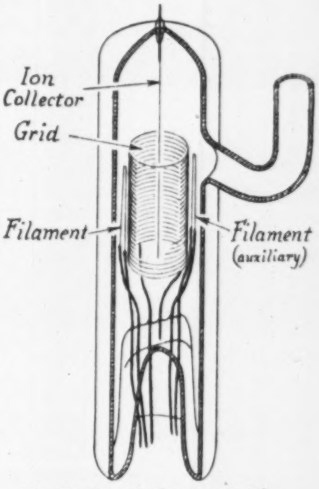

Fig. 25. Bayard-Alpert gage tube.

(2) The *Philips* Gage.—Distinctive features of this ionization gage are: (a) instead of thermionic emission, use of a cold cathode made of thorium or zirconium; (b) magnetic deflection whereby the electrons travel in a spiral path hundreds of times longer than the cathode-anode distance, causing a corresponding increase in the ionization-probability factor and hence an easily-measured plate current even at pressures as low as 0.01 micron.

(3) The *"Alphatron."*—In this gage the ionization is not produced by electrons but by alpha particles emitted from a pellet of radioactive material such as a radium compound. Thus, what may be called the volumetric ionization is constant, but the total ionization—measurable as the ion current—is proportional to the pressure.

9. COMPARATIVE CHARACTERISTICS

The outstanding characteristics of the various classes of vacuum gages are summarized with extreme brevity in Tables II and III. In the foregoing text, only the most important limitations and advantages of the various classes of vacuum gages have been mentioned. There are too many others for discussion in this chapter. They vary not only with the class and type, but with the design or make. It is not uncommon for two vacuum gages, outwardly alike and bought and installed at the same time, to differ in their characteristics. Most cases of "customer dissatisfaction," however, probably began with hastily ordering the wrong type of gage, through unawareness of available types.

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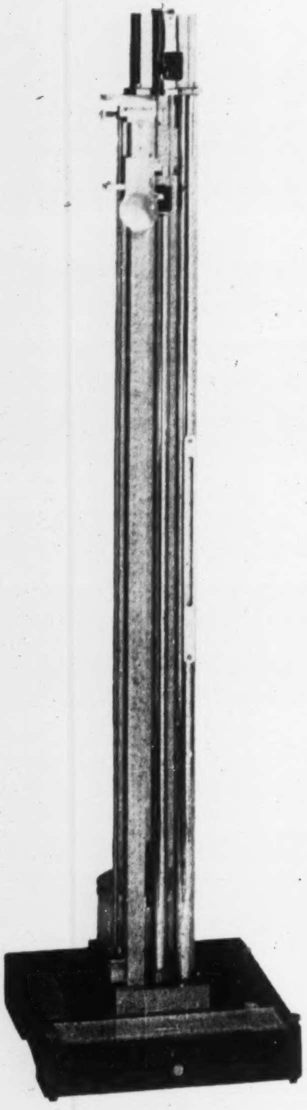

Type A-1 Barometer

TYPE A-1 BAROMETER (MANOMETER)

The Type A-1 Barometer is a precise working standard for the measurement of pressure altitude and absolute pressure. It incorporates the following major features: 1. Direct true pressure readings (no manual corrections). 2. Full range temperature and gravity compensation. 3. Precision-bore glass tube and cistern. 4. Chromium-plated engine-divided precision scale. 5. Choice of scale graduations (inches, millimeters, millibars, altitude, etc.). 6. Double-edged scale. 7. Internal tests to assure continued accuracy.

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The Micrometer Standard Barometer is designed for use as a primary pressure standard. In addition to the normal mercury column reading, the change in the mercury level in the cistern is read by means of a pressure sealed depth micrometer. Calculations are applied to the two readings to correct to units of true length and to correct for temperature and gravity errors. The result is a true pressure reading that is reliable to within a few hundredths of a millimeter of mercury.

Although more accurate than the Type A-1 Barometer, the calculations required make the Micrometer Standard less convenient to use.

PHOTO-SCANNER

The Photo-Scanner (accessory equipment) extends the utility and sensitivity of the Type A-1 Barometer. Sighting of the mercury column is accomplished by adjusting the vernier slide to center the needle of the large 4½″ null-type indicator. True pressure readings (corrected for temperature and gravity) are taken from the precision scale. Pressure changes are immediately indicated on the meter. Dual sensitivity provides full scale deviation of the null indicator for approximately .020″ (0.5mm) of mercury on low sensitivity; .004″ (0.1mm) on high sensitivity.

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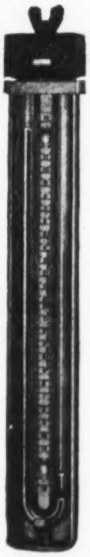
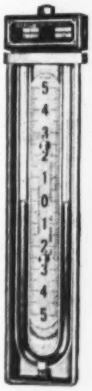


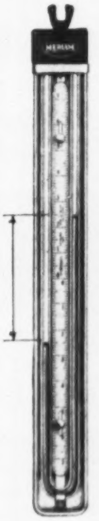
U-Type Absolute Pressure Gauge

For the measurement of *absolute pressures* from one millimeter of mercury to the equivalent atmospheric pressure. Of simple design—accurate and dependable. Gauge head fastens to body by a single wing nut. Available in wall or flush front mounting styles. Ask for catalog sheet C-1142 WM.

Clean-Out U-Type Manometer
(Model B-1169 WM)

Semi-steel clean-out head is removable from body frame for filling and cleaning U-tube. For line pressures up to 100 lbs. per sq. in. Large bore "pyrex" tubing 7/16" inside diameter gives flat indicating fluid meniscus. Bold ½" high scale numerals provide for distant reading. Ask for catalog sheet B-1169 WM.

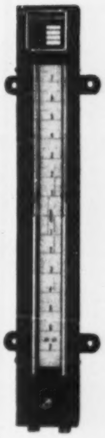




U-TYPE MANOMETERS

The Clean-Out Manometer (at left) for line pressures up to 100 lbs. per sq. in. A wing nut permits the Manometer body and tube to be disconnected from the head — the tube cleaned with a brush furnished or tube replaced, and the instrument reassembled without disconnecting the head section from the piping. Send for Bulletin No. 1.

The Model A-995 WM Manometer for line pressures up to 400 lbs. per sq. in. These instruments are built with heavy walled annealed straight Pyrex tubes, gland packed top and bottom in steel end blocks and clamped to the body at fixed intervals to prevent distortion. Catalog Sheet A-995 WM gives complete details.



Well Type Manometer
(Table Mounting)

For portable service in the field, production testing, or in the laboratory. Glass tubing is gland packed at each end block and is supported at spaced intervals to prevent tube distortion. Also available for wall mounting, pipe mounting, and flush front panel mounting. Ask for catalog sheet A-203 TM.

Well Type Manometer
(Front-of-Board Mounting)

The instrument body channel, scale, and indicating tube mount to the front of the panel; instrument well mounts behind panel. Connections are made behind the mounting panel. Provides an accurate, quick, and direct method of measurement. Ask for catalog sheet A-324 FB.

WELL-TYPE MANOMETER

Model A-275 WM (at left) is a direct reading type for line pressures up to 150 lbs. per sq. in. Standard construction; ranges — from 6" to 24". Wall mounted type shown; also available in flush mounting. Ask for Catalog Sheet A-275 WM.

SIGHT FEED BUBBLER

This Sight Feed Bubbler with 2⅛" dia. bowl of Pyrex glass is good for line pressures up to 50 lbs. per sq. in.; of plastic, for pressures up to 100 lbs. Sturdily built with brass or semi-steel body. Supplied in ring type (shown) and strap type. Needle valve controls bubbler rate. Ask for Bulletin 21.

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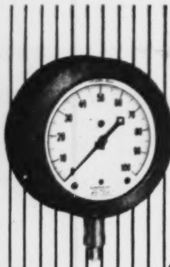

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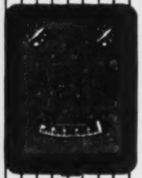

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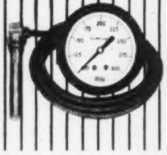

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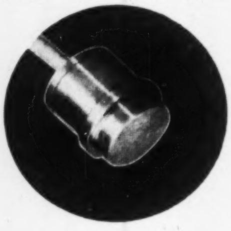

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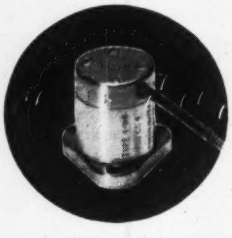

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All Consolidated pickups are described completely in Bulletin CEC 1552-X10. We will gladly send you a copy.

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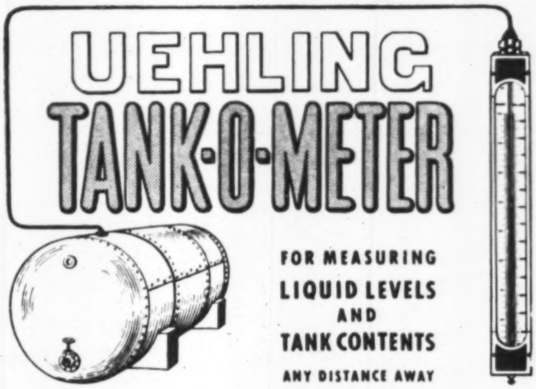

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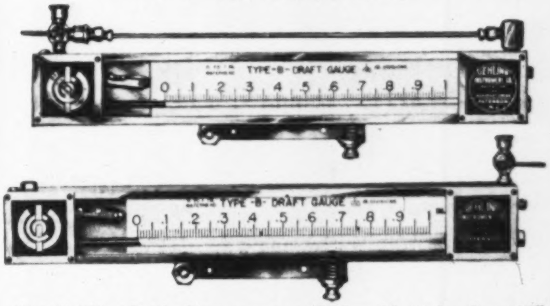
For Differential Pressure



The Uehling Draft Gauges are available with scales from 10" to 40" and waterheads ranging from 1" to 8". Scales are graduated for every 1/100" of waterhead. Each instrument is housed in a durable aluminum case with glass front and adjustable scale. They are extremely accurate as each instrument is individually calibrated. Furnished for draft, pressure, or differential pressure. *Send for Bulletin* 1146.

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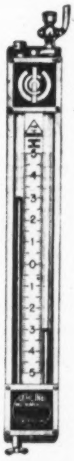

Uehling U-Tube Pressure and Vacuum Gauges consist of straight Pyrex tubes with a bottom metal connecting base, housed in aluminum case with glass front.

Each instrument has an external micrometer scale adjustment, zero check cock, and drain valve.

Scale lengths from 10" to 100".
Four indicating fluids.
Special calibration on request.
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TEL-FLO METER
MODEL A
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MERCURIAL BAROMETERS

With vernier scale. Can be furnished with the same style case as used with Uehling pressure and vacuum gauges, illustrated here.

PRESSURE AND VACUUM GAUGES

Meet the most exacting requirements and combine accuracy, reliability, simplicity and durability. Housed in durable Aluminum cases with glass fronts. Standard instrument covers a range of 31 inches of mercury head. A catch-all for trapping visibly shows any condensate in the connecting line. Each scale has a knurled micrometer screw adjustment. A simple means is provided for cleaning the Pyrex manometer. May be calibrated in any desired units for pressure or vacuum and may be provided with a plus or minus scale to read either vacuum or pressure on the same instrument. Length to suit any range. Greater flexibility is made possible by choice of either mercury or one of three other indicating fluids.
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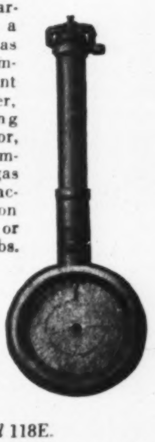
APEX CO$_2$ RECORDER



Actuated by changing partial vacuum developed in a separate device, known as the CO$_2$ meter. The complete standard equipment consists of one CO$_2$ Meter, one type M Recording Gauge, one type Z Indicator, "Pyro-Porus" filter, one sampling pipe holder, one gas dryer, one motor driven vacuum pump and one suction regulator. Where steam or water is available at 60 lbs. pressure or more, an aspirator may be substituted for the motor driven vacuum pump which materially reduces the price of the equipment. The Apex CO$_2$ Recorder makes a continuous record.
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MERCURY COLUMN ABSOLUTE PRESSURE INDICATORS

Uehling Mercury Column Absolute Pressure Gauges are designed for exacting requirements of modern engineering practice, and combine accuracy, reliability, simplicity, and durability. Used with all processes where extremely accurate absolute pressure determinations are essential. Can furnish catch-all for trapping and showing any condensate. Standard scale lengths of 7" to 100", graduated in 1/10" of mercury absolute pressure or in pounds or in equivalent metric units.
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COMBINED BAROMETER AND VACUUM RECORDER

Records barometric pressure and vacuum on same chart. Distance between the two recorded lines represents the absolute pressure. Permanent accuracy and remarkable legibility are the outstanding characteristics of this recorder. Accuracy is obtained by the employment of the mercury column principle and consequently this recorder has the same high degree of accuracy as the mercury column indicator. It employs no springs, diaphragms, or multiplying levers, therefore holds its calibration permanently without readjustment.
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UEHLING VACUUM RECORDER

Same as above, without barometric pen.
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★ Weldless heat treated Bourdon tube maintains precise calibration.

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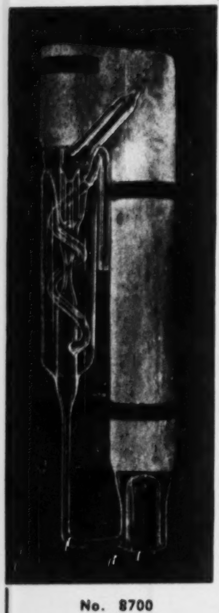

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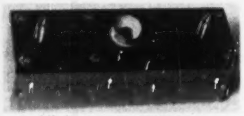
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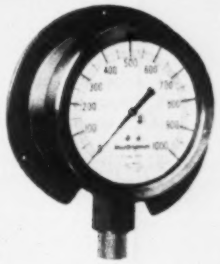

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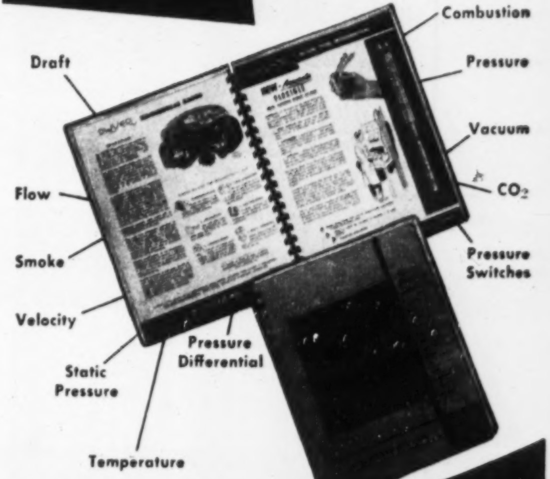

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CHAPTER IV

DIMENSIONAL GAGING AND INSPECTION

By ROGER L. GEER

EVERY component of commercial goods produced has limitations as to its size, form and alignment which must be heeded to assure not only interchangeability, but also the vital proper functioning of the item. Dimensional Gaging and Inspection determine to what precision the components agree with prescribed limitations on detail drawings.

Interchangeability necessitates limiting gages for controlling dimensions of parts. Since gages are made by human beings, and often on tools similar to those used for making the parts, certain precautions are necessary to restrict the gagemaker's product. Common practice is to allow the gagemaker 10% of the part dimension tolerance as his deviation from the ideal size for the gage. Table 1 shows the American Standards for Fixed Gages.

Gaging equipment must be calibrated to a universally acceptable standard. Hardened steel gage blocks have been produced in quantity so that every shop can afford at least one set. These **blocks are available in accuracies of 2, 4, or 8 millionths of an inch per inch at** size combinations from 0.010 to 80 inches by increments of 0.0001 inch. National Bureau of Standards calibration of such blocks should be obtained before using so that they may function as master standards for calibrating inspection equipment, and size standards for setting up comparator-type gages. Expansion of these blocks is comparable to that for commercial steels (0.0000064 in./in./°F.) Temperature corrections are necessary only in very precise work and when non-ferrous materials are being inspected.

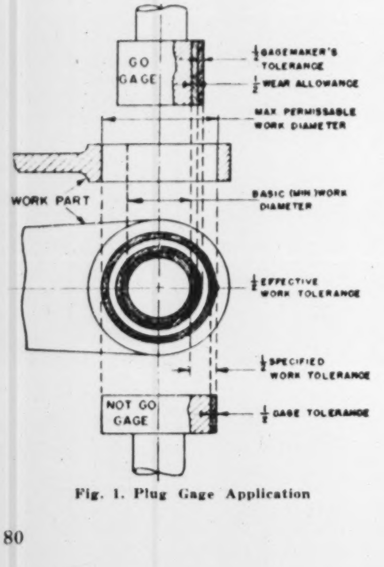
GO GAGE
½ GAGEMAKER'S TOLERANCE
½ WEAR ALLOWANCE
MAX PERMISSABLE WORK DIAMETER
WORK PART
BASIC (MIN) WORK DIAMETER
½ EFFECTIVE WORK TOLERANCE
½ SPECIFIED WORK TOLERANCE
NOT GO GAGE
½ GAGE TOLERANCE

Fig. 1. Plug Gage Application

Since gage blocks are extremely convenient to use, they now are used in many shop set-ups. Here the blocks are subjected to considerable wear. This wear may be reduced by the use of tungsten carbide wear blocks (0.050 or 0.100 in. thick) on the ends of a stack.

Chromium-plated blocks have been helpful, and now full sets of carbide blocks are available. Carbide has 2.9 microinch expansion coefficient as compared to 6.5 for steel, and specific gravity of 16 against 7.6 for steel. Although the cost of carbide blocks is about five times that of steel blocks, they have over fifty times the life of the latter.

Inspection operations are "non-productive" tasks in the cost accounting of a product. It is imperative that the device selected for controlling the quality of the part be economical as well as reliable. This choice will be controlled by:

1—Precision required

2—Nature of surfaces (abrasive, smooth, or resilient)

3—Temperature of surface

4—Type of surface (internal or external)

5—Form of surface (flat or curved)

6—Volume of production

7—Weight of part

8—Type of inspection (single or multiple items)

9—Place of inspection (at machine or bench)

10—Nature of inspection (indicating, sorting, or controlling)

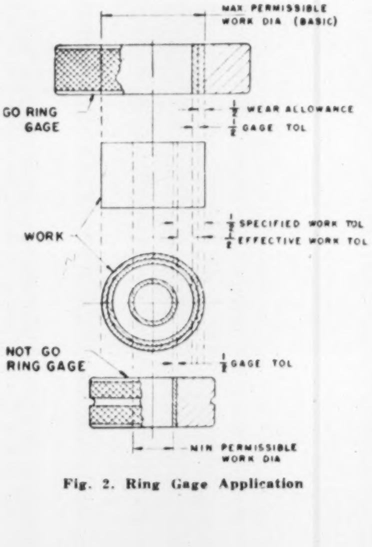
MAX PERMISSIBLE WORK DIA (BASIC)
GO RING GAGE
½ WEAR ALLOWANCE
½ GAGE TOL
WORK
½ SPECIFIED WORK TOL
½ EFFECTIVE WORK TOL
NOT GO RING GAGE
½ GAGE TOL
MIN PERMISSIBLE WORK DIA

Fig. 2. Ring Gage Application

MECHANICAL FIXED GAGING

Fixed gages simulate limiting sizes of mating parts. Plugs are used to check holes, and holes (rings) examine shaft-like elements. Special forms are available for slots, splines, tapers, and threads. Plug and ring gages (Figs. 1 & 2) permit complete scrutiny of the part-revealing taper, out-of-roundness, bellmouth, and the like. Parts whose form do not permit access by a ring **gage can be examined by the snap gage (Fig. 3). Snap gages are end-measuring only, and do not reveal inaccuracies as readily as the** ring gage; **multiple applications being** necessary to **thoroughly inspect a part.**

Fixed gages are available in several **standard sizes and forms.** Too often **they are abused by applying too great pressure during gaging,** or using after **having been nicked or burred. Feel is important, and these gages** should not **be used on parts with** tolerances under **0.001 in. When setting snap gages,** cylindrical masters **should be used if the parts** have curved surfaces.

MECHANICAL INDICATING METHODS

Indicating types of instruments reveal the value of a dimension or show the magnitude of deviation from ideal size. Vernier calipers permit both internal and external dimensions to be measured on the same instrument. Micrometer calipers depend upon the precision of their lead screws for reliable measurement. Both of these manually-operated devices have their readings varied by inconsistent contact pressure.

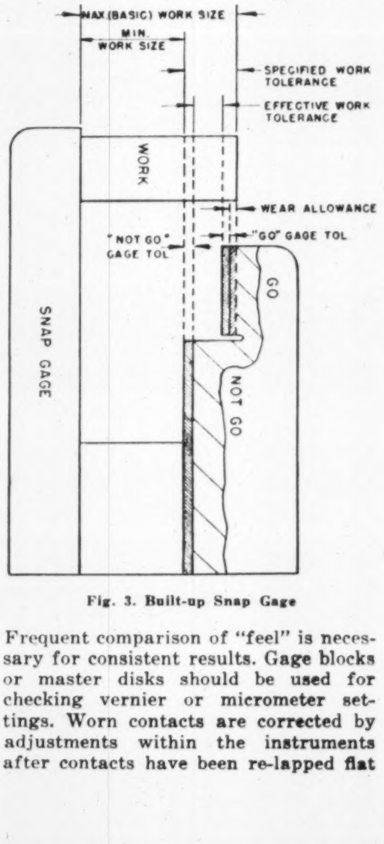
MAX (BASIC) WORK SIZE
MIN. WORK SIZE
SPECIFIED WORK TOLERANCE
EFFECTIVE WORK TOLERANCE
WORK
WEAR ALLOWANCE
"NOT GO" GAGE TOL
"GO" GAGE TOL
SNAP GAGE
GO
NOT GO

Fig. 3. Built-up Snap Gage

Frequent comparison of "feel" is necessary for consistent results. **Gage blocks or master disks should be used for** checking **vernier or micrometer** settings. **Worn contacts are corrected by adjustments within the instruments after contacts have been re-lapped flat** and parallel. Measuring machines, with accessories, are capable of handling work 80 in. long with variable contact pressures to 2½ lbs. Their lead screws are of higher precision than those in shop micrometers.

COMPARATIVE READING METHODS

Mechanical comparators assure consistent and reliable readings regard-

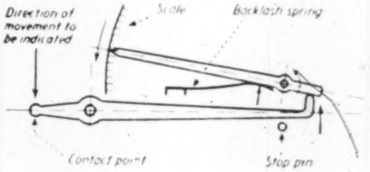

Fig. 4. Simple Mechanical Amplifier

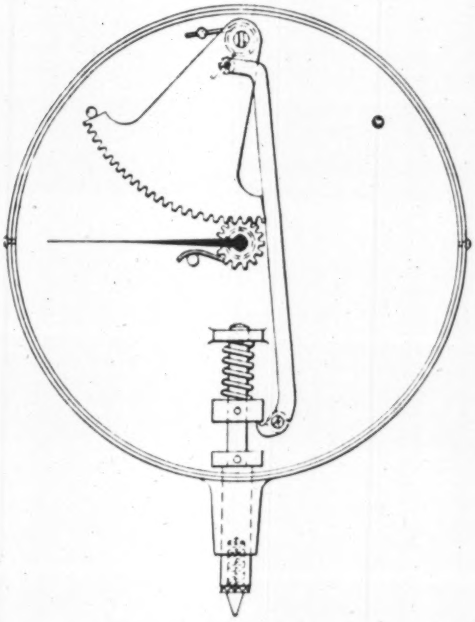

Fig. 5. Mechanical Dial Indicator

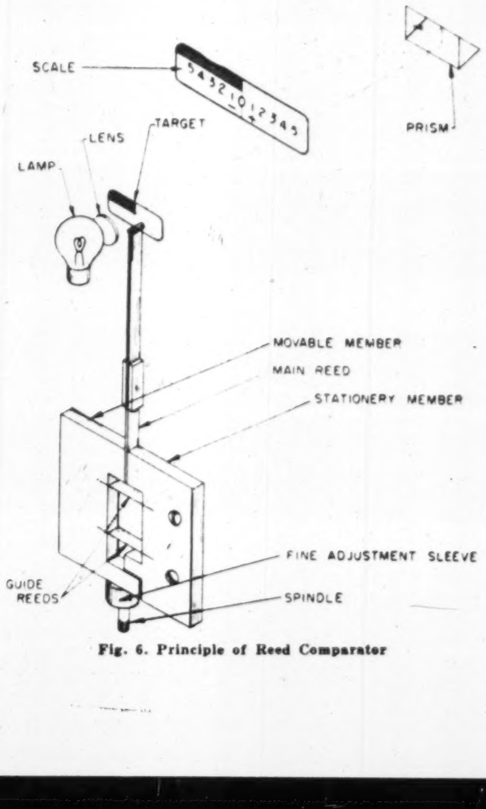

Fig. 6. Principle of Reed Comparator

TABLE 1. PLUG AND RING GAGE TOLERANCE
AMERICAN GAGE DESIGN STANDARD

Above	*To and Incl.*	(*Male Gages Only*) XX	X	Y	Z	(*Ring Gages Only*) ZZ
0.029—	0.825	0.00002	0.00004	0.00007	0.00010	0.00020
0.825—	1.510	0.00003	0.00006	0.00009	0.00012	0.00024
1.510—	2.510	0.00004	0.00008	0.00012	0.00016	0.00032
2.510—	4.510	0.00005	0.00010	0.00015	0.00020	0.00040
4.510—	6.510	0.000065	0.00013	0.00019	0.00025	0.00050
6.510—	9.010	0.00008	0.00016	0.00024	0.00032	0.00064
9.010—	12.010	0.00010	0.00020	0.00030	0.00040	0.00080

XX—Precision lapped (plugs or male masters only)
X—Precision lapped plugs or rings
Y—Lapped plugs or rings
Z—Ground and polished (grinding marks may be in evidence)
ZZ—Ground only (for rings only)

TABLE 2. FIXED MECHANICAL SIZE GAGES

Type	*Sizes*	*Accuracy*	*For Work Tol.*
Solid Plug	0.002 to 12.010 in.	to 0.00005 in.	0.001 in.
Adjustable Plug	2.500 to 12.500 in.	0.00010 in.	0.005 in.
Adj. Length Gage	3.000 to 60.000 in.	0.00010 in.	0.003 in. to 12 in. 0.005 in. to 30 in. 0.010 in. to 40 in. 0.015 in. to 60 in.
Ring Gage	0.029 to 12.010 in.	to 0.00005 in.	0.001 in.
Solid Snap Gage	0.002 to 60.000 in.	0.00020 in.	0.002 in.
Adj. Snap Gage	0.002 to 12.000 in.	0.00030 in.	0.003 in.
	Any	0.00020 in.	0.005 in.
Flush Pin Gage	0.002 to 8.010 in.	0.00005 in.	0.0001 in.
Setting Discs	0.010 to 20.000 in.	(AA)0.000002 in.	0.000005 in.
Gage Blocks	by 0.0001 in. steps	(A)0.000004 in.	0.000010 in.
		(B)0.000008 in.	0.000050 in.

TABLE 3. FIXED MECHANICAL GAGES FOR ALIGNMENT OR FORM

Type	*Approx. Size Ranges in Inches*	*Accuracy in Inches*
Surface Plate		
Cast Iron	3½x4 to 36x68	0.0003 in 24
Ceramic	4 to 24 dia.	0.0001 in 24
Granite	8x12 to 96x192	0.00005 up to 24x36 0.0002 for larger sizes
Toolmaker's Flat	4 to 6 dia.	0.000010 flat
Optical Flat	2 to 10 dia.	0.000002 flat
Straight Edges		
Steel, knife edge	2 to 6	0.0001 in 6
Steel, rectangular	12 to 72	0.0002 in length
Cast Iron	18 to 180	0.0005 in length
Parallels		
Solid Steel	5/16x¼x5 to 1½x3x12	0.0002 (size), 0.0001 (parallel) 0.0004 (size), 0.0002 (parallel)
Solid Cast Iron	1½x3x24 to 4x8x36	0.0005 (size), 0.0005 (parallel) 0.0005 (size), 0.0005 (parallel)
Cast Iron, Box	4x4x6 to 6x14x16	0.0005 (size & square in 6), & 0.00025 (parallel in 6)
Angle Irons		
Cast Iron	2½x3x4	0.0001 square
Universal	3x4x5 to 8x9x16	0.0003 square and parallel
Squares		
Steel	1 to 36	0.0001 in 6 square
Cylindrical	3, 4, and 5 diameter	0.0001 in 6 square
V-Blocks	1-3/8x1-3/8x1⅛ to 4x3x3	0.0002 square and parallel
Sine Bars	5, 10, and 20	0.00002 (length), 0.000025 (edges parallel to studs)
Angle Gage Blocks	0 to 90 degrees by 1 sec.	¼ second of arc

TABLE 4. DIRECT-READING TYPES FOR SIZE

Type	*Capacity*	*Scale Grad.*	*Accuracy*
Vernier Caliper	0 to 6, 12, 18, 24, 36 and 48 inches	0.001 in.	0.001 in. per in. 0.002 in. per ft.
Micrometer Caliper	0 to ½ and 0 to 60 inches by 1-inch steps	0.001 in.	0.0002 in. per in.
Supermicrometer	0 to 10 inches	0.0001 in.	0.00005 in. per in.
Measuring Machine	0 to 80 inches	0.00001 in.	0.000005 in. per in.

TABLE 5. DIRECT-READING TYPES FOR ALIGNMENT

Type	*Capacity*	*Accuracy*
Protractor Vernier Bevel	12-in diameter for 180°	½ deg.
Protractor Mechanical	12-in diameter for 180°	5 min.
Dividing Head Optical	24-in. diameter for 360°	spindle run-out 0.0004 in. 30 sec. in 360°
Dividing Head	12-in. diameter for 360°	spindle run-out .000025 in. 2 sec. in 360°

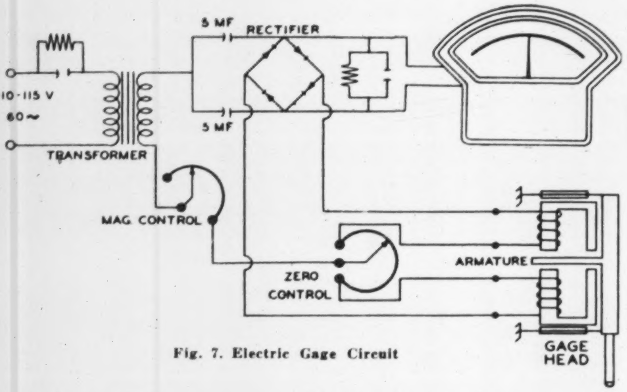
110-115 V
60~
TRANSFORMER
5 MF
RECTIFIER
5 MF
MAG. CONTROL
ZERO
CONTROL
ARMATURE
GAGE
HEAD

Fig. 7. Electric Gage Circuit

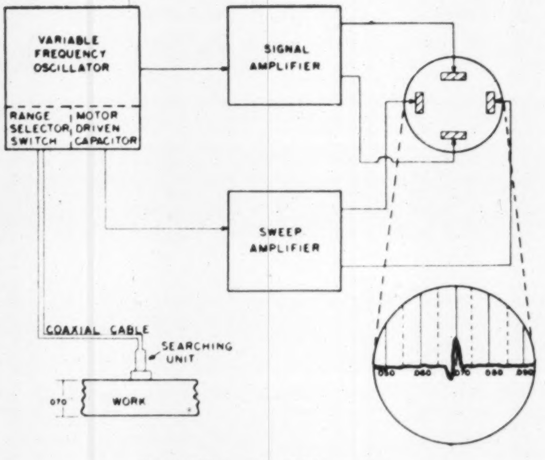
VARIABLE
FREQUENCY
OSCILLATOR
RANGE
SELECTOR
SWITCH
MOTOR
DRIVEN
CAPACITOR
SIGNAL
AMPLIFIER
SWEEP
AMPLIFIER
COAXIAL CABLE
SEARCHING
UNIT
.070
WORK
.050
.060
.070
.080
.090

Fig. 8. Ultrasonic Thickness Gage

TABLE 6. MECHANICAL COMPARATORS

Type	*Range*	*Scale Grad.*	*Magnification*
Test Indicators			
Bellcrank Type	0.010 in.	0.001 in.	50:1
Compound Lever	0.020	0.001	35:1
	0.001	0.0001	400:1
Gear train type	0.010	0.0001	500:1
Dial Indicators	0.050 to 0.250	0.001	to 500:1
	0.010 to 0.050	0.0001	to 1000:1
Steel Reed, with	0.008	0.0001	to 500:1
light lever	0.00025	0.000002	to 20,000:1

less of the operator, since contact pressure is constant. Some models provide adjustment of this pressure from ¼ to 16 oz. to suit conditions and materials being inspected. Magnifications of contactor displacement enable small size changes to be observed with ease. Amplifying levers are often attached to "fixed gages" to permit tolerance reading and establish uniformity of contact presure. A simple amplifier (Fig. 4) can be improved to a compact unit (Fig. 5) with greater range.

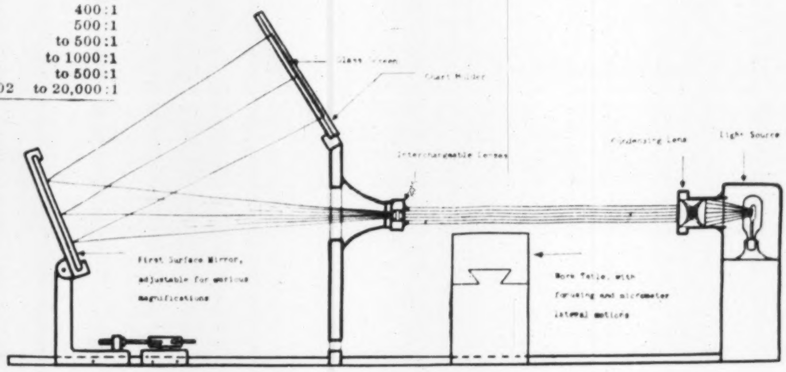
Glass Screen
Chart Holder
Interchangeable Lenses
Condensing Lens
Light Source
First Surface Mirror, adjustable for various magnifications
Work Table, with focusing and micrometer lateral motions

Fig. 9. Optical Projection Comparator

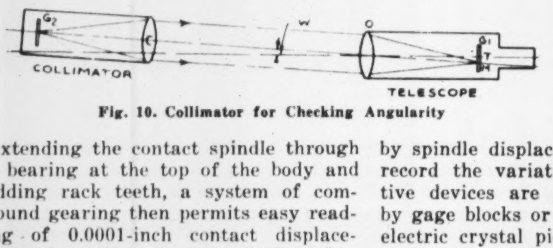
G2
C
W
O
G1
T
M
COLLIMATOR
TELESCOPE

Fig. 10. Collimator for Checking Angularity

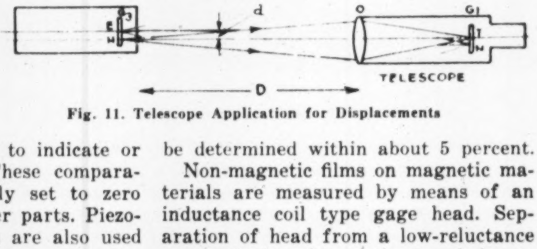
E
G3
M
d
O
G1
I
M
D
TELESCOPE

Fig. 11. Telescope Application for Displacements

Extending the contact spindle through a bearing at the top of the body and adding rack teeth, a system of compound gearing then permits easy reading of 0.0001-inch contact displacements in ranges up to one inch. Other mechanical elements are used, including the reed "frictionless" scheme. These are often augmented by an optical (Fig. 6) or electronic magnifier.

ELECTRICAL METHODS

Electrical methods permit remote location of the indicating scheme away from dirt, vibration, and possible mechanical injury. Capable of high magnification of contact displacement, they afford easy connection to process controlling devices, signal lights or sounds, or sorting transfers.

The usual circuit is the familiar bridge arrangement, using inductance, resistance, or capacitance in the gaging head. Fig. 7 shows an inductance type. Contact spindles may also be arranged to flex a metal strip to which strain gages have been cemented, or to vary a capacitance. Electronic amplifiers magnify the unbalance created by spindle displacement to indicate or record the variation. These comparative devices are initially set to zero by gage blocks or master parts. Piezoelectric crystal pick-ups are also used in gage heads for fine measurements. Magnifications from 700:1 to 25, 000:1 permit observations in size from 0.0001 in. to 0.00001 in. Estimation of partial scale divisions is justifiable if care is exercised and temperature control is used.

Wall thickness of hollow parts, when inner wall is inaccessible, may be determined by impressing ultrasonic vibrations on the exposed surface and observing reflected wave pips (Fig. 8) in an oscilloscope. Contact with at least 1 sq. in. of surface no rougher than 200 microinches r.m.s. is required. Practically all metals, glass, unfilled plastics, and some rubbers up to 4 in. thick can be inspected to an accuracy of 2 percent of material thickness.

A somewhat similar method is to impress vibrations through a quartz crystal element and ascertain the resonant frequency of the object. This permits thicknesses up to 12 inches in metal to be determined within about 5 percent.

Non-magnetic films on magnetic materials are measured by means of an inductance coil type gage head. Separation of head from a low-reluctance material (by the coating) unbalances the bridge circuit sufficiently to indicate thickness on a calibrated microammeter. Its range is from 0.00012 to 0.500 in. at 10 percent accuracy. Plated coatings are also detected by measuring the torque required to separate a calibrated magnet from the work. Readings on coatings above 0.002 in. can be made to 10 percent precision.

Gamma rays are used on walls up to 0.750 in. thick by beaming them on work at about 45°. Pick-up of back-scattered radiation gives material thickness readings to 3 percent accuracy. This portable scheme (25 lbs.) does not detect pinholes or fine cracks.

OPTICAL METHODS

Using shadow-picture principles, a projection comparator (Fig. 9) permits examination of part profiles to 0.0001 in. and angles to 5 min. By adding surface illumination, reflected images of embossed surfaces such as type faces are inspectable. Parts are generally fixtured on the work table, reference lines properly aligned with a chart screen layout, and the checking of many dimensions at one setting is obtained as quickly as the eye can observe the magnified silhouette of the part. Highly accurate charts, showing limiting sizes, are used on screens from 6 to 30 in. diameter at magnifications from 10x to 100x.

Small areas may be observed on a toolmaker's microscope. Dimensions to 4 in. by 0.0001 in. and angles to 1 min. are possible. Other microscopes with filar heads permit readings to 0.00002 in. at 50x. Cathetometers permit reading vertically to 0.002 in. at distances of 60 feet.

Telescopes are used in collimator applications as seen in Figs. 10 and 11 to detect tilt to within 6 sec. at 50 ft., or displacements to 0.003 in. at 80 ft. Light rays from central point of G_2 leave collimator lens C in a beam parallel to collimator axis, enter lens O at an angle W. Rays are focused at M, off the telescope axis. TM is proportional to angle W, and independent of distance between the two devices. Lateral displacement does not affect the image, except that light from collimator must reach lens O. The use of a displacement scale, either in collimator or a target plug (Fig. 11) functions by being displaced sideways off the telescope axis so that point H lies on this axis. Telescope is focused on G_3 by knob K. Image H is formed at T, coincident with central mark of G_1, while center point E of G_3 images at N. TN is a measure of lateral displacement EH of the axes, and is independent of any inclination. TN is inversely proportional to separation of units. Actual scale is at G_3 and its image is compared with a simple cross at G_1. When d equals one division on scale G_3, TN will appear as one division, regardless of the separation D. Increase of D will decrease imaged division. Sensitivity decreases with separation of the units. Quiet air between units is necessary for good results in collimators as well as cathetometers.

Telescopes as used in transits can establish alignments to 0.001 in. in 60 ft. Levels of the surveyor's type can check to 0.024 in. in 100 ft.

Optical flats from 1 to 10 inches in diameter, flat to one millionth of an inch, provide laboratory precision in checking surfaces for flatness and also comparison of gages. Monochromatic light (generally 0.0000232 in. wavelength) impressed on a flat causes interference bands to appear as seen in Fig. 12. When surface observed is not flat, bands appear in a contour map pattern, indicating nature of surface and degree of error. Fig. 13 illustrates a use of an optical flat for comparative measurement of pitch diameter of a thread gage. Light interference may also be applied to obtain absolute values of a dimension. This involves use of a series of light wavelengths to obtain measurements to one-millionth precision.

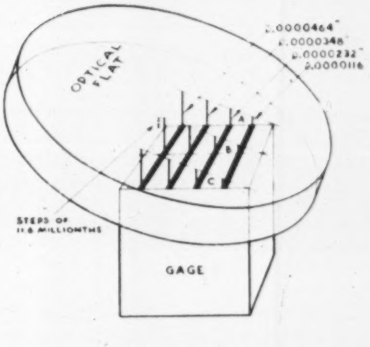
OPTICAL FLAT
.0000464"
.0000348"
.0000232"
.0000116
A
B
C
STEPS OF
11.6 MILLIONTHS
GAGE

Fig. 12. Light Interference Bands

PNEUMATIC METHODS

Air gaging permits non-contact inspection at high precision on parts whose surfaces may be fragile, porous, or of extremely fine finish. It is not generally applicable for work tolerances over 0.005 in.

One or more tiny jets in a special plug or snap-type gage impinge air upon the part, and variations in air escaping when parts are applied to the gage are registered either in a back-pressure or rate-of-flow instrument. Jet tips are below the surface of the piloting surface of the gage, and are protected from wear or injury. Special forms are available for

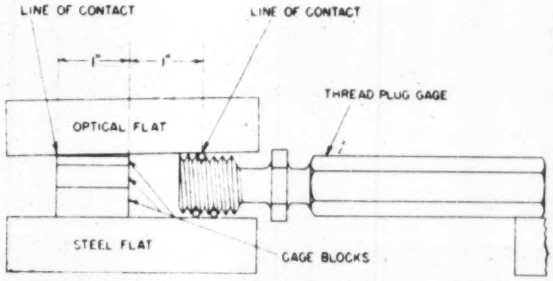
LINE OF CONTACT
LINE OF CONTACT
1"
1"
THREAD PLUG GAGE
OPTICAL FLAT
STEEL FLAT
GAGE BLOCKS

Fig. 13. Optical Flat Used to Check Pitch Diameter of Thread Gage

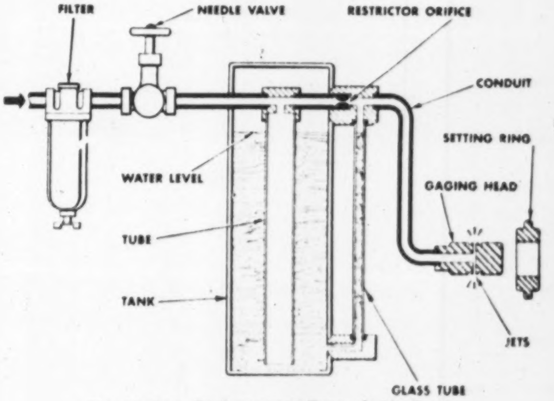
FILTER
NEEDLE VALVE
RESTRICTOR ORIFICE
CONDUIT
SETTING RING
GAGING HEAD
WATER LEVEL
TUBE
TANK
JETS
GLASS TUBE

Fig. 14. Low Back-pressure Type of Air Gage

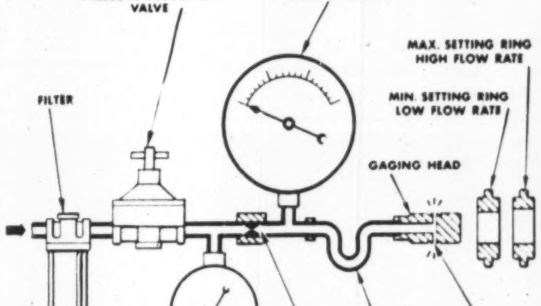
PRESSURE REGULATOR VALVE
INDICATING GAGE
MAX. SETTING RING HIGH FLOW RATE
MIN. SETTING RING LOW FLOW RATE
FILTER
GAGING HEAD
CONDUIT
JETS
CONSTANT PRESSURE INDICATOR
RESTRICTOR ORIFICE

Fig. 15. High Back-pressure Type of Air Gage

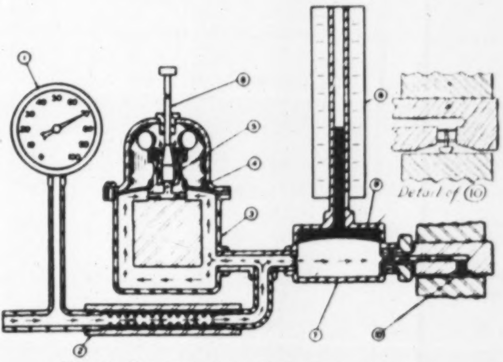
①
②
③
④
⑤
⑦
⑩
Detail of ⑩

Fig. 16. Manometer-type Back-pressure Air Gage

inspecting gun rifling, splines, slots and the like.

The back-pressure type (Fig. 14) was originally a low-pressure device, using a water column. Water level in the glass tube is depressed as back pressure increases when a closer-fitting part is gaged. Tank height limits this model to pressure of about 1 psig.

This circuit is extremely sensitive, hence part surfaces must be clean and smooth for valid readings. High-back-pressure and flow type comparators remove normal dirt and cutting fluids at gaging points.

Mechanical indication of back pressure (Fig. 15) using 30 psig. exit pressure allows inspection of oily parts during or after machining. Long conduits incur time lags on indicating gage. Fig. 16 illustrates another pressure system. Line pressure air (1) is fed through restrictors (2) to balancing chamber (3). Balance is adjusted by pin (6), controlling orifice (5) mounted on a flexible disk (4). Air also passes to measuring column chamber (7) where air-liquid compartments are separated by disk (9) and then on to gage head (10). When work is presented to the gage head, the jeweled contactor is depressed towards the jet in the head, restricting air escape. Increased pressure in the circuit produces a rise in the liquid column (8) proportional to the change in part size. Surplus air is bled to atmosphere through orifice (5). Back-pressure technique is also applied to a pneumatic 4-arm bridge circuit. This compact unit is calibrated by one set-standard, instead of the conventional two, to 0.00005 inch.

Magnification for pressure types varies from 750:1 to 10,000:1, permitting scale graduations to show as fine as 0.00001-inch size variation.

Flow-type circuits use similar gage heads, are set up in the same manner using master rings or plugs, yet permit use of conduits as long as 50 feet before suffering from noticeable lags at the indicator. Magnifications up to 100,000:1 are possible, making readings of 0.000001 inch readily seen. Constant-pressure flow-rate meters of the rotameter type (Fig. 17) change magnification (1,000:1 to 100,000:1) by changing the tapered bore of the tube. By-pass bleeders permit quick zeroing and magnification adjustments. This is important when gage wear occurs, for it permits continued use by simply altering valve settings. Rotameter tubes can be grouped closely together, thus making possible the inspection of as many as thirty dimensions by glancing at the row of tubes. Such multiples would not be feasible with dial type devices, that are usually limited to three dimensions. Rotameter-type gages with special gage heads have been adapted to measure surface roughness, size of textile fibers, etc.

Air flow may also be measured by Venturi section (Fig. 18). Velocities at the outlets of tubes 1 and 2 will differ,

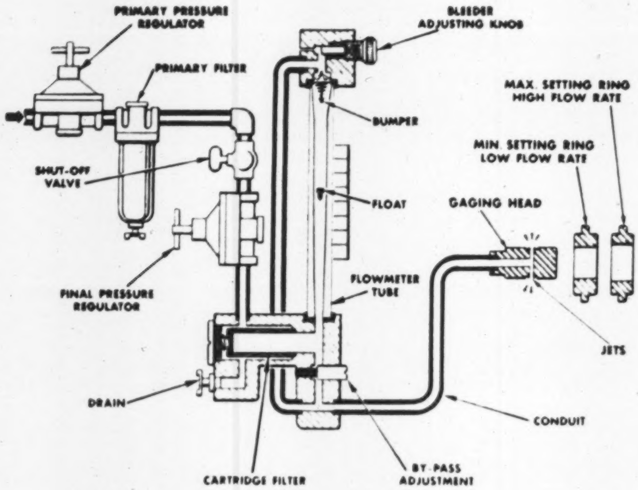
PRIMARY PRESSURE REGULATOR
BLEEDER ADJUSTING KNOB
PRIMARY FILTER
MAX. SETTING RING HIGH FLOW RATE
BUMPER
MIN. SETTING RING LOW FLOW RATE
SHUT-OFF VALVE
FLOAT
GAGING HEAD
FINAL PRESSURE REGULATOR
FLOWMETER TUBE
JETS
DRAIN
CONDUIT
CARTRIDGE FILTER
BY-PASS ADJUSTMENT

Fig. 17. Rotameter (flow) Application to Air Gaging

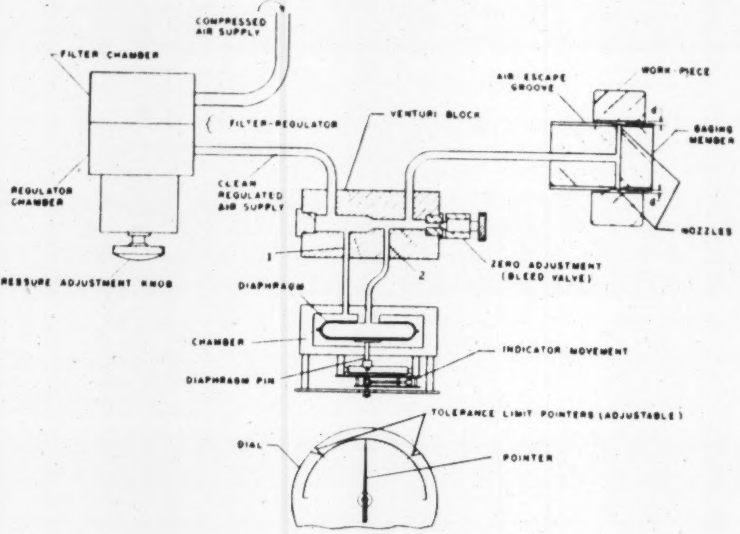
COMPRESSED AIR SUPPLY
FILTER CHAMBER
WORK PIECE
AIR ESCAPE GROOVE
VENTURI BLOCK
FILTER-REGULATOR
GAGING MEMBER
d
REGULATOR CHAMBER
CLEAN REGULATED AIR SUPPLY
NOZZLES
1
2
ZERO ADJUSTMENT (BLEED VALVE)
PRESSURE ADJUSTMENT KNOB
DIAPHRAGM
CHAMBER
INDICATOR MOVEMENT
DIAPHRAGM PIN
TOLERANCE LIMIT POINTERS (ADJUSTABLE)
DIAL
POINTER

Fig. 18. Venturi (flow) Type of Air Circuit

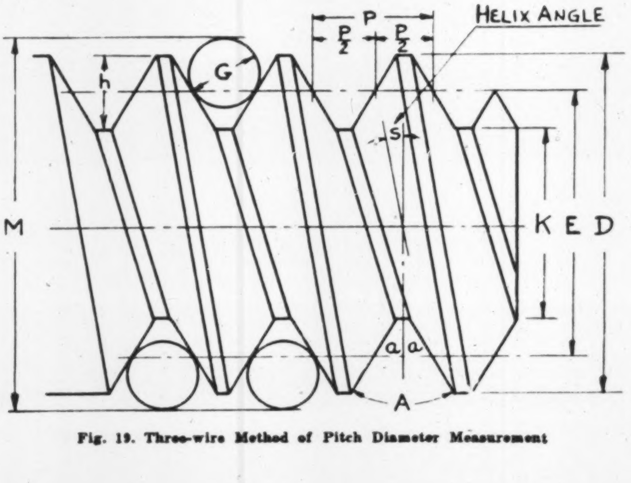
P
P/2
P/2
HELIX ANGLE
G
h
S
M
KED
a
a
A

Fig. 19. Three-wire Method of Pitch Diameter Measurement

Roughness height = 16 microinches
Waviness height = 0.0005 in.
Lay = Circumferential
Roughness width = 0.030 in

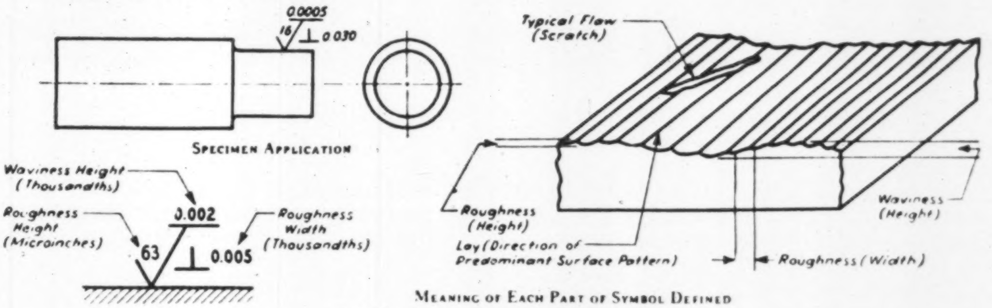
0.0005
16
0.030
SPECIMEN APPLICATION
Waviness Height (Thousandths)
Roughness Height (Microinches)
0.002
63
0.005
Roughness Width (Thousandths)
Typical Flaw (Scratch)
Roughness (Height)
Lay (Direction of Predominant Surface Pattern)
Waviness (Height)
Roughness (Width)
MEANING OF EACH PART OF SYMBOL DEFINED

Fig. 20. Surface Roughness Designation

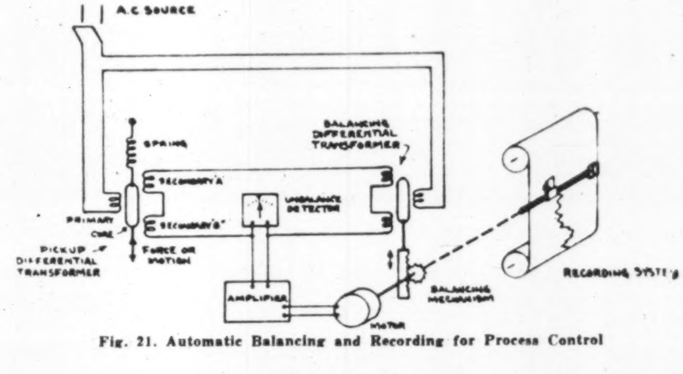
A.C. SOURCE
SPRING
SECONDARY "A"
SECONDARY "B"
PRIMARY
CORE
PICKUP DIFFERENTIAL TRANSFORMER
FORCE OR MOTION
BALANCING DIFFERENTIAL TRANSFORMER
UNBALANCE DETECTOR
AMPLIFIER
MOTOR
BALANCING MECHANISM
RECORDING SYSTEM

Fig. 21. Automatic Balancing and Recording for Process Control

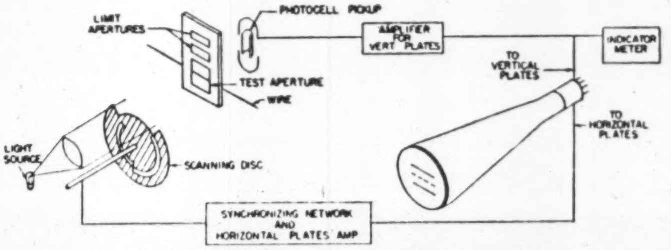
LIMIT APERTURES
PHOTOCELL PICKUP
AMPLIFIER FOR VERT. PLATES
INDICATOR METER
TO VERTICAL PLATES
TEST APERTURE
WIRE
TO HORIZONTAL PLATES
LIGHT SOURCE
SCANNING DISC
SYNCHRONIZING NETWORK AND HORIZONTAL PLATES AMP

Fig. 22. Photoelectric Inspection of Continuous Strip Material

causing a pressure differential on the diaphragm, whose motion is transmitted to dial pointer through a mechanical linkage. Gage nozzle insertion in a part decreases the flow (velocity) of air in the circuit. Minute changes in jet-work clearance are amplified in the Venturi-diaphragm circuit.

Pneumatic comparators are also used on parts that are porous or rough (above 63 microinches r.m.s.) or have interrupted bores. Contact-type gaging heads, using ball or blade contacts that restrict air exit from jets behind them, permit extending these comparators to wider fields of application. These units can be used in any position and are so compact that they can be fixtured to check multiple dimensions on odd-shaped parts with ease.

SPECIAL TECHNIQUES

Threads are inspected by adding thread-like elements to fixed gages, micrometers, and comparator contacts. Projection comparators are excellent for examining thread profiles—except pitch diameter, the most important dimension. Pitch diameter is determined, indirectly, by a "3-wire" method (Fig. 19) using suitable end-measuring instruments. Neglecting helix angle effect (less than 0.0001 in.) for any number of threads per inch (n) of American National Form:

$$\text{Pitch Diameter} = M + \frac{0.86603}{n} - 3G$$

Gears are inspected on equipment especially designed by that industry. Examination of gears for eccentricity, backlash, tooth profile, helix angle, load distribution and noise is made on comparator-type machinery involving the use of master gears or assembly mates. Indicating and recording models are available.

Surface Roughness Designations are shown in Fig. 20. Standard specimen blocks for shop use by sight and feel comparisons range from 2 to 500 microinches. Surface appearance is affected by type of machining process, hence several surfaces of identical roughness are included in the sets. Direct measurement of surface quality is obtained by using piezoelectric or inductance type pick-ups, using a tracer stylus of 0.0001 in. or 0.0005 in. radius. Oscillographic recording or simple indicating instruments, actuated by amplifiers of the tracer signals, complete the apparatus. Optical schemes are also available, but lack portability and scanning capacity.

AUTOMATIC INSPECTION—
PIECE-BY-PIECE

Large-volume production can be inspected by any of the conventional comparator schemes, and by adding automatic handling mechanisms, parts may be conveyed into reject or accept compartments. Accepted parts may vary considerably from one another, yet assemble satisfactorily if mates have been selected according to a predetermined sorting pattern that groups parts of like variation from ideal size. Handling mechanisms are tailor-made to suit each part.

A simple device for sorting balls consists of two bevelled straight edges, separated to form a wedge-shaped slot, and inclined so that the balls may slowly roll down the widening slot. Containers beneath the slot are spaced as desired to catch the balls at intervals of size. Sphericity may be checked by an inclined plate bounce test, or repeated passes on the slot device.

Gaging heads are full electrical or pneumatic-electrical; air being used on highly finished parts to gage the parts and also actuate relays to electrically divert gaged parts into size differences as fine as 0.00001 in. Electronic sorting circuits use thyratron tubes, preset to fire at slightly different voltages that are originated in the electrical gaging head. Multiple gaging heads are often employed to realize inspection rates of 4,000 units per hour or more, depending on the complexity of the part.

Ultrasonics has been applied to the inspection of cavity volumes, such as cylinder bores. Using the familiar organ pipe resonance principle, it affords an accuracy of 1 part in 1500 at production rate of 100 pieces per hour.

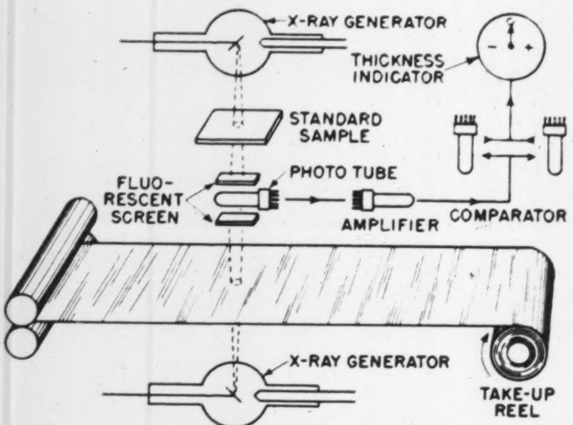

Fig. 23. Continuous Inspection of Strip by Single-beam X-ray

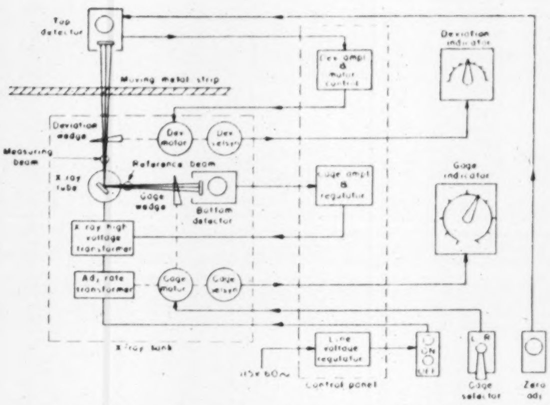

Fig. 24. Continuous Inspection of Strip by Double-beam X-ray

AUTOMATIC INSPECTION—CONTINUOUS STRIP

Modern strip and wire fabrication is too speedy for manual or intermittent inspection. Sizing is extremely important as uniformity is vital to successful subsequent processing operation on the material.

Control of material rigid enough to permit use of contact rollers can be gaged to 0.0005 in. by using a floating gage head. The gage may indicate variations on a dial indicator, or actuate sizing devices in the processing machinery. Electrical gaging, with damped instruments, permits control to 0.0001 in. These work excellently on coaters and extruders. Fig. 21 shows a circuit for balancing process equipment when size variation actuates a contactor that moves the core of a differential transformer pick-up.

Air jets are suitable where the material cannot be contacted because of its fragility, resilience, or surface quality. By using balanced diametrically-opposed jets, some flutter of the material is permissible even at high speeds. Readings as fine as 0.000002 in. are possible.

A photoelectric measuring device (Fig. 22) contains a measuring aperture whose effective area is varied as thin strip or thread-like material passes by it. A scanning disk rotates between apertures and photocell, exposing each of three apertures in sequence. This results in three voltage pedestals being fed to the amplifier, in timed sequence, synchronized with the disk. The three voltages are each amplified in a common circuit and applied to the vertical deflection plates of the oscilloscope. Sweep voltage is applied to the horizontal plates so that termination of each viewing cycle occurs simultaneously with the scanning disk alternations from one aperture to another. This device will perform in bad atmospheres if the aperture is kept clear by an air blast. Controlling or indicating devices may be added to inspect material up to 1.2 inches thick at 0.0001 in. accuracy. Flutter as much as 0.40 inches is permissible, but it reduces the accuracy of instrument to 0.001 in.

X-rays are absorbed by a material, depending upon its density. Fig. 23 shows a means for measuring sheet material by using a single beam to detect the unabsorbed radiation. A two-beam arrangement (Fig. 24) passes the reference beam through the gage wedge, striking a detector unit where a phototube is excited by fluorescent material. Output is a measure of the difference between intensity of reference beam and a standard within the detector. Material from 0.001 to 1 inch thick may be examined at an accuracy of about 2 percent.

Beta-rays use a weighing principle. Strip material from 0.0002 to 0.145 inches thick and textiles from 5 to 150 oz. per sq. yd. can be accommodated at 2 percent accuracy. Speed of travel of the material does not affect its precision, but films of moisture, oil, or a protective coating will be registered in the gage. Beta rays are emitted from a small radioactive source, chopped 90 times per second, and sent through the material into an ionization chamber receiver for energy measurement. The 90-cycle signal produced is compared to a reference signal from a generator operated from the chopper shaft. Life of the source is estimated at over 25 years, and its radiation at one foot is less than the maximum allowed for safety.

SPECIAL INSTRUMENTS FOR THE BLIND

Precision work and measurements, heretofore considered feasible only by sighted people, can be accomplished by the blind. Special designs utilize the faculties which can be used by sightless persons.

A standard one-inch micrometer caliper plus a simple vernier sliding bar and a collar provide a means of measuring sizes accurately within 0.0002 in. by touch. Raised lines on the vernier and the collar replace the usual numbers. The "mike" is set to the part to be measured and size to the nearest 0.025 in. is determined by sliding the vernier bar up against the lower edge of the knurl, then locating, with the fingernail, the two raised lines of the vernier most nearly in line. Measurement to less than 0.001 in. is accomplished by feeling the position of the raised lines on the collar with relation to a fixed point on the bar.

A special design of height gage uses increments of one inch, obtained by a spring-loaded pawl in accurately cut slots in a beam. The increments are subdivided into 0.100 in. increments by means of ten precise slip gages. These gages are pivoted to a saddle and are swung in line with a micrometer spindle as needed. Further subdivision of the measuring head is accomplished by a notched micrometer screw to permit readings to 0.001 in. This scheme is also applicable to vernier calipers.

Comparator-type gages of the visual type can also be made convenient. Where the indication of the gage is in the form of red-orange-green lights to denote undersize-OK-oversize, the instrument can be altered by substituting a sound generator, which provides three tones to replace the three lights of the conventional gage. Operators listen either through an ear plug or from a small speaker. Such comparators may be set to inspect to within twenty-five millionths of an inch.

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(5) "Precision Measurement in the Metalworking Industry," 2 vols. Syracuse University Press, Syracuse, 1952.

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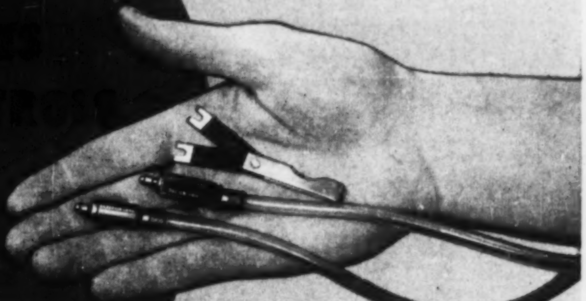
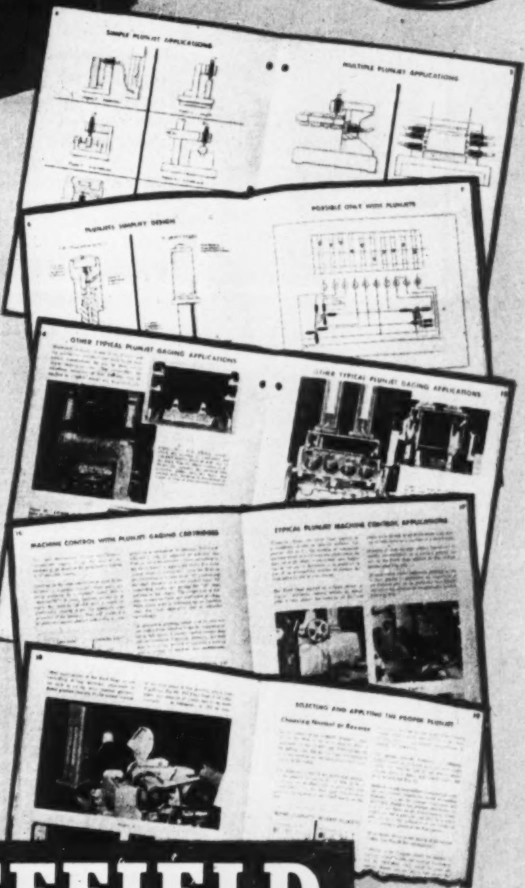


"PLUNJET" GAGING CARTRIDGES



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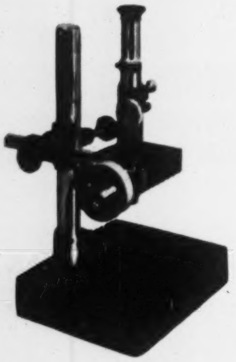

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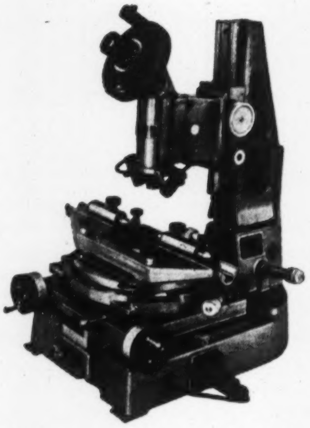

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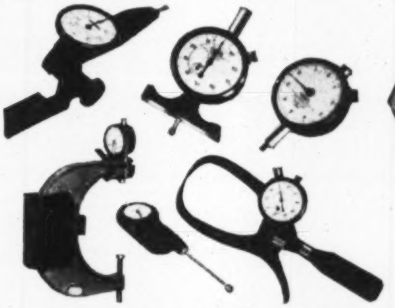

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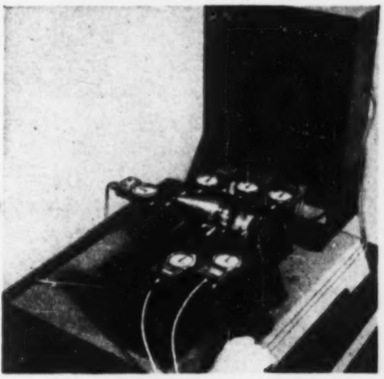

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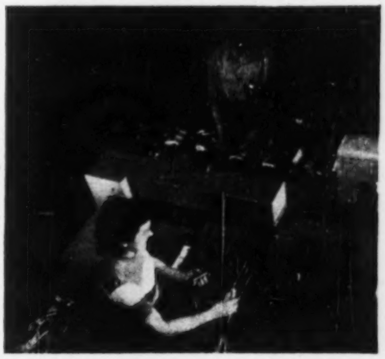

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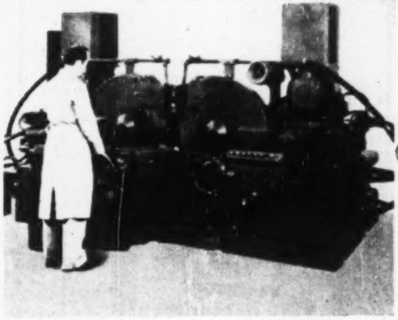

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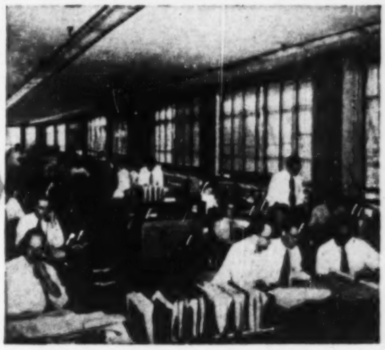

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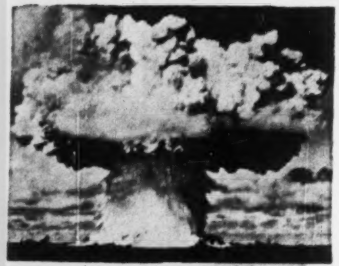

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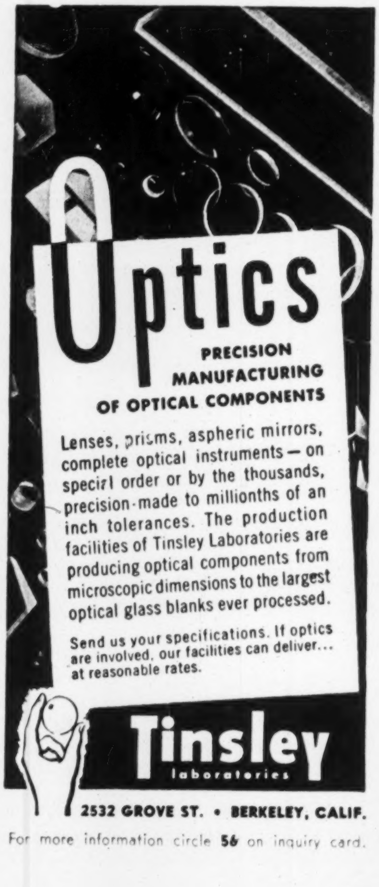

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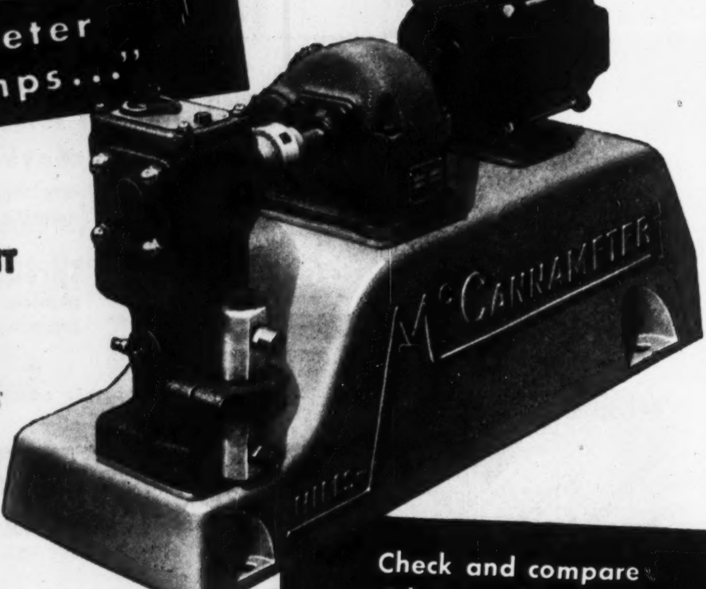

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CHAPTER V

FLOW-RATE MEASUREMENT

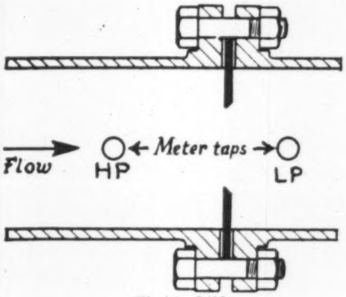
By ROBERT L. GALLEY

INTRODUCTION

THIS chapter deals with the most common types of flow meters as applied to a closed conduit or pipe line.

In any measurement, use must be made of accepted standards. In measuring flow rate there are only two measured values—time and quantity. Time is defined in internationally accepted units of seconds, minutes, and so forth; quantity is defined in many standards of both volume and weight.

Flow-rate measurement.—The "measurement" of flow rate means the indication or recording of the instantaneous flow of a gaseous or liquid stream in a pipe line. The measurement is expressed in volumetric or in gravimetric units per time unit—for example, gallons per minute, cubic feet per second, or pounds per hour.



Flow
Meter taps
HP
LP

Fig. 1. Orifice

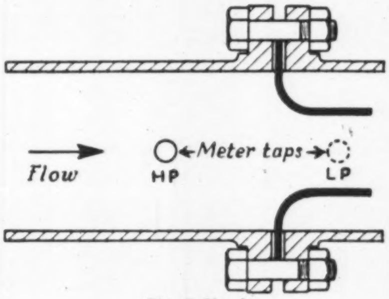


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Fig. 2. Nozzle

The measurement of *quantity* of fluid in pounds, gallons, cubic feet, and so forth, which is the summation, totalization, or integration of the flow, may or may not be made along with the measurement of flow rate.

Flowmeters.—A flowmeter is a device or instrument which measures the *rate* of flow of a liquid or gaseous fluid in a conduit and which produces a visual indication of the rate of flow.

Classification of flow-rate meters.—The following outline lists the best-known classes and types of flowmeters:

A. Head meter (variable differential-head with constant area of flow passage)
  1. Venturi tube (with variations)
  2. Flow nozzle (sometimes known as a rounded-approach orifice)
  3. Sharp-edge thin-plate orifice (fixed)
  4. Pitot tube (with variations)
  5. Annular orifice
  6. Moving orifice
  7. Adjustable orifice
  8. Centrifugal (impact elbow, scroll-case)
B. Variable-area meter (with constant head or pressure drop)
  1. Rotameter
  2. Swinging vane (force)
  3. Piston or plug
C. Rotating member
  1. Anemometers (propeller or rotor or turbine)
  2. Rolling-ball (spinner) meters
D. Electrical
  1. Heater type (thermal)
  2. Electromagnetic
  3. Sonic
E. Mass-flow

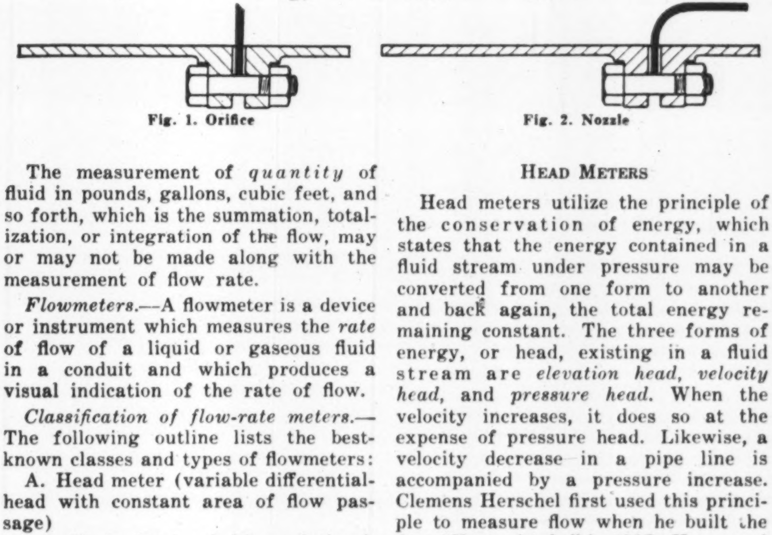
HEAD METERS

Head meters utilize the principle of the conservation of energy, which states that the energy contained in a fluid stream under pressure may be converted from one form to another and back again, the total energy remaining constant. The three forms of energy, or head, existing in a fluid stream are *elevation head*, *velocity head*, and *pressure head*. When the velocity increases, it does so at the expense of pressure head. Likewise, a velocity decrease in a pipe line is accompanied by a pressure increase. Clemens Herschel first used this principle to measure flow when he built the first "Venturi tube" in 1887. He proved that a consistent relationship existed between the velocity and the static pressure through the tube. Thus, the modern head meter operated by the pressure, or *head*, differential through a flow element came into existence.

The square-root law of flow.—The differential head bears a square-root relationship to the flow rate because the velocity head (kinetic energy) is proportional to the square of the flowing velocity. It can be shown that the change in velocity through a pipe-line restriction *of any shape or type* can be expressed as the square-root of the pressure drop. This leads to the flow formulae given later in this chapter.

Head-meter elements.—A head meter consists of at least two parts—(1) a restriction, or primary device, in the pipe line, which alters the velocity of the fluid stream and produces a differential pressure, and (2) a measuring element, which measures the differential pressure drop. The pressure drop is translated into flow-rate readings in several ways.

The restrictions that produce the differential pressure are classified in four types—orifice, nozzle, Venturi, and Pitot. An *orifice* (Fig. 1) is a hole in a thin disk that is inserted between flanges in the line. A *nozzle* (Fig. 2) is an orifice with a flared or rounded approach section. A *Venturi*, or *Venturi tube*, (Fig. 3) is a fitting consisting of a "throat" preceded by a convergent section and followed by a di-



Meter taps
HP
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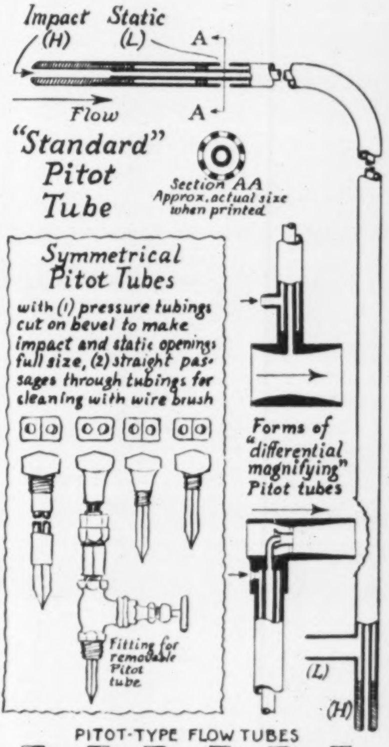
Fig. 3. Venturi



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A
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Flow
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Forms of "differential magnifying" Pitot tubes
(L)
(H)
PITOT-TYPE FLOW TUBES
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Fig. 4. Pitot Tube Variations

vergent section. A *Pitot tube* (Fig. 4) is a velocity probe that receives the full impact of the stream and converts the entire velocity head into pressure head.

A Pitot tube points straight into the stream; it measures the velocity only where the Pitot opening occurs. Pitot tubes are not used much at present except for low-pressure gas work, such as fans, blowers, and so forth, where their asset—low pressure loss—is important. Each Pitot tube installation must be calibrated individually by a pipeline traverse.

There are numerous variations of shapes and combinations of the four basic types of restriction, as shown in Figs. 4 and 5. However, for most flowmeter work, one of the four basic types described usually does as well as one of the elaborate adaptations.

Choice of restriction. — Flowmeter users often ask how to choose between types of restriction. *Use an orifice whenever possible.* On average applications where the fluid is relatively free of suspended solids, and where pumping costs or pressure losses are not a serious factor, the thin-plate square-edged orifice is outstandingly superior and is used almost exclusively. It is the most accurate on service to which it is adapted and more research data is available on it than on any other type. It can be easily made and duplicated—there are no contours to match, and the thickness, up to certain limits, is relatively unimportant. It is relatively inexpensive, is convenient to install, remove, and replace, and is easy to clean. Its only drawback is the inefficiency with which it produces pressure drop, because it consumes more pressure in the piping system than other types. However, this factor is unimportant unless the application is one in which every ounce of pressure loss is important.

Accuracy in the primary device depends solely on the accuracy of the flow-coefficient value and on the care used in making and installing the device.

In applications where the orifice accumulates foreign deposits from the fluid stream, a nozzle or venturi tube is recommended.

The choice between the nozzle and the Venturi tube is not a matter of accuracy, but of (1) piping layout (the Venturi tube is long and bulky), (2) cost (the nozzle is much cheaper), and (3) pressure loss (the Venturi tube is more efficient and consumes less pressure than the nozzle). Fig. 6 shows pressure loss through an orifice, a nozzle, and a Venturi tube. For an orifice, the pressure loss (expressed as a percentage) is nearly equal to $(1-B^2)$ where B (Beta ratio) equals orifice diameter divided by pipe diameter. The graph shows the advantage of a Venturi over both orifice and nozzle in pressure loss, whereas the nozzle is only slightly better than an orifice. Don't confuse pressure *loss* with pressure *drop*. The *drop* is the measured differential pressure read by the flowmeter, the *loss* is that part of the drop which, due to turbulence, is not recovered when the fluid stream returns to full pipe diameter.

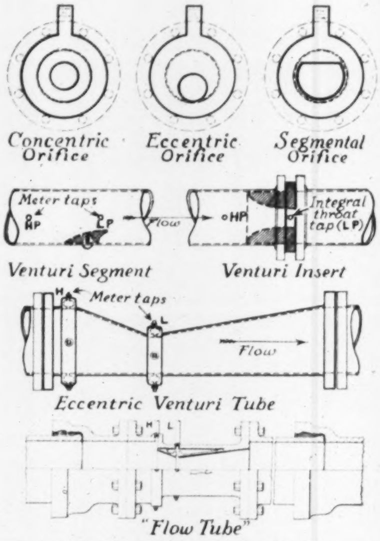


Fig. 5. Types of primary elements.

The relative characteristics of orifices, flow nozzles, Venturi tubes, and Pitot tubes are shown in Table I.

FLOW FORMULAE

All types of primary elements follow the same square-root law. The only difference in the calculation is in the *numerical constant*, or multiplier. The basic flow formula is: *flow rate equals a numerical constant times the square root of pressure differential times the square root of fluid density.*

This is the basic head-meter formula and applies to all conditions of pipe size, fluid, pipe taps, shape of primary element, and so forth. All of these factors are combined in the numerical constant.

The derivation of the numerical constant involves (1) a numerical factor, (2) the flow coefficient (not discharge coefficient), and (3) the square of the hole or throat diameter.

The *numerical factor* takes into account (1) the conversion of hole or throat area from square feet to square inches, (2) the square root of twice gravity—that is, $\sqrt{2g}$, (3) the conversion of pressure drop from feet of metered fluid to inches of water, or to whatever terms are desired, and (4) for gas flow, a correction (called the "compressibility factor") for change of gas density as it flows through the opening.

The *flow coefficient* is an experimentally-derived number (roughly between 0.6 and 1.0), which is based on experimental research. Flow coefficients are now standardized in this country and abroad for various sizes of orifices, nozzles, venturis, and so forth. They can be found in the technical publications of scientific bodies such as the American Society of Mechanical Engineers, the American Gas Association, and the Bureau of Standards. This coefficient, which is usually designated by the letter "K," can be thought of as the turbulence factor, or the efficiency with which velocity changes are converted to pressure-drop changes. The smoother the flow through the orifice or nozzle, the higher the co-

TABLE I—CHECK LIST OF PRIMARY DEVICES

Application Considerations	*Orifice*	*Flow Nozzle*	*Venturi Tube*	*Pitot Tube*
Accuracy	Excellent	Good	Excellent	Good for one-point measurement. For measurement of total flow, a velocity traverse is necessary for good accuracy.
Suitability for Liquids Containing Solids in Suspension	Poor	Good	Excellent	Unsatisfactory
Pressure Recovery	Poor	Poor	Good	Excellent
Suitability for Viscous Flows.	Fair	Good	Good	Requires a velocity traverse of the conduit.
Low cost in large sizes.	Good	Fair	Poor	Excellent
Low cost in small sizes.	Excellent	Fair	Poor	Good
Suitability for Liquids Containing Traces of Vapors.	Excellent — if flow is in upward direction through a vertical conduit.	Excellent — if flow is in upward direction through a vertical conduit.	Excellent	Fair
Suitability for Gases Containing Traces of Condensate.	Excellent — if flow is in a downward direction through a vertical conduit.	Excellent — if flow is in a downward direction through a vertical conduit.	Excellent	Fair
Ease of changing Capacity.	Excellent	Fair	Poor	Impossible

efficient; the more turbulent the flow, the lower the coefficient. A venturi tube has a coefficient very close to unity, whereas a flat-plate orifice has one between 0.6 and 0.7. The venturi-tube, therefore, produces a differential pressure more efficiently than the orifice. The flow coefficient is found by flowing a liquid through the device under test, and by weighing the amount passed during a given time. When the weighed amount of fluid is divided by the theoretical amount obtained from the area of opening and the velocity through the opening, the quotient equals the flow coefficient. Published coefficients are tabulated according to pipe size, pressure-tap spacing, ratio of hole diameter to pipe diameter, and Reynolds number. Reynolds number is explained later in this chapter.

The square of the hole or throat diameter is used in expressing the area of the fluid stream passing through the opening. An example shows how the flow formula is developed for a particular orifice, nozzle, or venturi.

EVOLUTION OF THE FLOW FORMULAE

This development is for incompressible fluids (liquids) only, because a gas expands in flowing through a restriction, thus causing "compressibility" errors due to large drops in low-pressure mains. Another factor not considered in this development is the error due to thermal expansion or contraction of the hole. This error occurs when the temperature of the flowing fluid is not the same as the temperature of the hole when it was measured.

Step 1.—*Evaluation of numerical factor for any orifice, nozzle, or venturi.*—The conversion of hole diameter in inches to hole area in square feet requires the use of the factor $\pi/(4\times144)$, or 0.00545.

Another factor used is $\sqrt{2g}$, or 8.02. The differential head of flowing fluid in feet is converted into inches of water at 68 F. by use of the factor $\sqrt{62.32/12}$, or 2.28.

The factors are combined to give the numerical factor as follows: *Numerical factor* for flow rate in lbs. per sec. equals

$$0.00545\times8.02\times2.28 = 0.0997$$

Therefore, the numerical factor in lbs. per hr. equals

$$0.0997 \times 60 \times 60 = 358.9$$

The factors 0.0997 and 358.9 are in common use in many flow formulae for head meters.

Step 2.—*Evaluation of numerical constant for a specific orifice.*—Consider a particular pipe-line installation where the hole diameter is, say, 3.000 inches and the flow coefficient is, say, 0.6342.

Numerical constant for flow rate in lbs. per sec. $= 0.0997\times0.6342\times(3.000)^2 = 0.569.$

Step 3.—For the same specific orifice in the same pipe-line installation, the flow rate at any instant in lbs. per sec. is

$$0.569\times\sqrt{\text{liquid density (lbs. per cu. ft.)}}\times\sqrt{\text{pressure drop (inches of water)}}$$

Step 4.—Assuming, for illustration, that a liquid having a density of 64.0 lbs. per cu. ft. is flowing, and that the pressure drop at any instant is 100 inches of water, then the flow rate equals

$$0.569\times\sqrt{64.0}\times\sqrt{100} = 45.5 \text{ lbs. per sec.}$$

As it is inconvenient to consult tables of flow coefficients to calculate flow for a given orifice installation, flowmeter manufacturers have devised "short-cut" working formulae, nomographs, slide-rules, and so forth, to aid in rapid solution of flow problems. All of these aids are based on some variation of the basic flow formula: Flow-rate = Numerical Constant $\times\sqrt{\text{Fluid Density}}\times\sqrt{\text{Pressure Drop}}$. The author's favorite working formula and curve for orifices, nozzles, and venturis are given in Fig. 7.

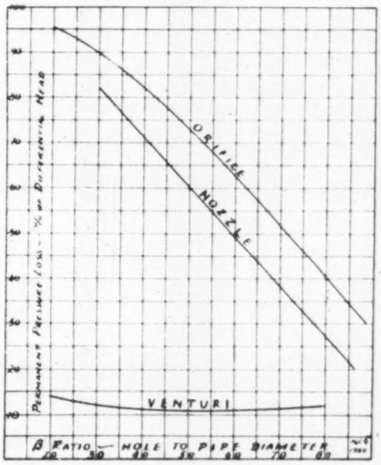


Fig. 6. Permanent pressure loss.

For compressible fluids (gases) the flow calculations are more complex and rigorous. However, for an approximation, the liquid formulae evolved above and also illustrated in Fig. 7 can be used to a fair degree of accuracy for any gas provided you select a pressure drop in inches of water numerically smaller than the upstream gage pressure in lbs. per square inch. The gas density (in lbs. per cu. ft.) must be known. The flow rate is calculated in pounds per second (or minute or hour). If the answer is required in cubic feet of gas at any desired base standard (such as 30 in. mercury and 60 F.), the weight flow-rate in pounds can easily be converted to volumetric flow-rate by using the proper gas density as a divider. The reader is referred to the publications of the American Gas Association (AGA) and the Southern California Meter Association (SCMA) for further details on gas measurement.

The expansion or contraction of the hole diameter in service is handled easily by applying the proper coefficient of thermal expansion to the measured diameter to obtain the actual hole diameter at the temperature of the flowing fluid.

Use of flow formula.—The capacity factor curve of Fig. 7 enables one quickly to calculate correct hole size for making an orifice installation. This capacity factor is made up of the numerical factor (358.9) for lbs. per hour, times the flow coefficient, times the square of beta ratio. Beta ratio (B) is the ratio of orifice hole diameter to *actual* pipe diameter at the inlet pressure tap.

To use the graph, first convert the desired flowmeter capacity to pounds per hour, if it is given in other units. Then choose the most desirable flowmeter pressure differential in inches of water. The square root of the product of fluid density and inches of water differential, multiplied by the square of pipe diameter (in inches), and all this divided into flow (in pounds per hour) gives the capacity factor. Then from the graph select the beta ratio corresponding to capacity factor thus found. Multiplying beta ratio by actual pipe diameter gives correct hole size.

To calculate flow rate from a measured pressure differential across a given orifice, work from known beta ratio to obtain flow rate in pounds per hour.

REYNOLDS NUMBER

The Reynolds number, which is named after Sir Osborne Reynolds, a British scientist, expresses the degree of fluidity of a flow stream. It equals ***velocity times hole diameter times fluid density, all divided by viscosity.***

The Reynolds number is inversely proportional to the fluidity of the stream. Therefore, a sticky fluid has a low Reynolds number (say 100), and a free-flowing fluid has a high Reynolds number (say 1,000,000).

The Reynolds number is a dimensionless number because all the units in the formula for the number cancel out. For example, if velocity is in ft./sec., and hole diameter is in ft., and density is in lbs./ft.^{3}, and viscosity is in lbs./ft.-sec., then

$$\frac{\text{ft.}}{\text{sec.}} \text{ x ft. x } \frac{\text{lbs.}}{\text{ft.}^3} \text{ x } \frac{\text{ft.-sec.}}{\text{lbs.}} = \frac{1}{1} = 1.$$

The Reynolds number is important because it has been proved that the flow coefficient is the same for a particular orifice in a particular pipe flange whether cold water, superheated steam, hot oil, compressed air, or any other fluid is flowing *provided the Reynolds numbers are equal.*

The Reynolds number is directly proportional to the velocity of the flow. It is proportional also to the diameter of the hole.

All flow-coefficient tables are set up and standardized according to Reynolds number as well as pipe size, beta ratio, and type of pressure taps used. This standardization has been adopted by scientific bodies all over the world.

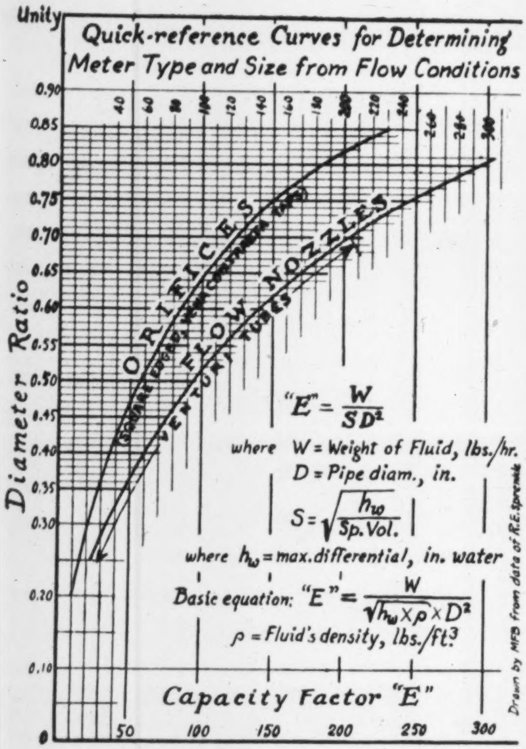


Fig. 7

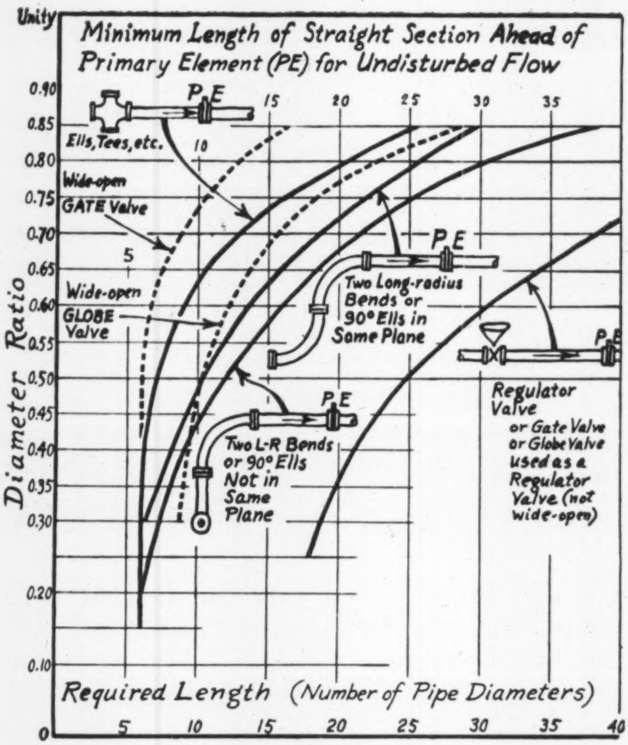


Fig. 10

Flow in any pipeline is either turbulent or streamlined (laminar). Thick, viscous fluids such as oils flow in laminar fashion, whereas lighter fluids such as water, air, and steam almost always flow in turbulent fashion. Laminar flow takes place in liquids with low Reynolds number (below about 10,000), whereas fluids with high Reynolds number flow turbulently. There is no sharp line of demarcation between laminar and turbulent flow; the transition from one to the other is gradual.

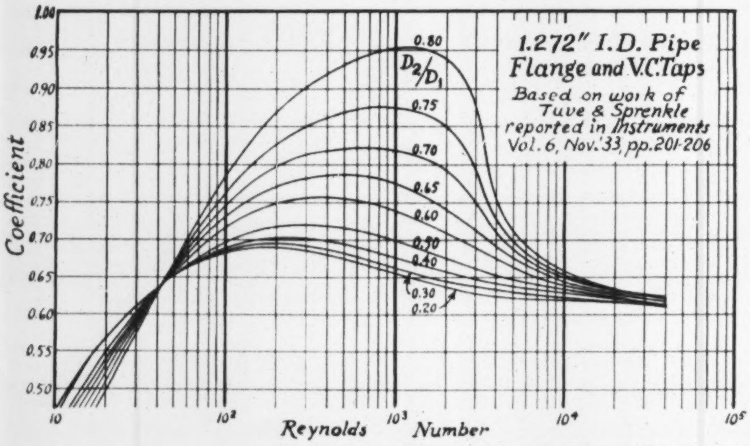
Most head-meter flows are turbulent and have high Reynolds numbers ranging from several thousand to several million. Fig. 8 illustrates the fact that for fluids with high Reynolds number the flow coefficient becomes fairly constant for any one size of orifice. This is fortunate because it means that the influence of the Reynolds number in calculating flow can usually be neglected. It is best, however, to quickly check the Reynolds number, using the formula below.

Reynolds-number formula.—Reynolds number equals 0.00424 times flow rate (in lbs. per hr.) divided by orifice diameter (in in.) and viscosity (in lbs. per ft.-sec.).

If viscosity is given in poises or centipoises, the viscosity can be converted to lbs. per ft.-sec. as follows: Viscosity in poises (dyne-sec. per sq. cm.) times 0.0672 equals viscosity in lbs. per ft.-sec.

If viscosity is given in stokes or centistokes, convert as follows: Viscosity in stokes (dyne-sec.-cm. per gm.) times specific gravity of the flowing fluid equals viscosity in poises.

The English units, rather than the metric units (poises and stokes) are preferred by many in calculating Reynolds numbers. Viscosity in Reynolds numbers is the *absolute viscosity.* Saybolt and other types of viscosimeters give readings in *kinematic* viscosity units (stokes and centistokes), which must be converted to absolute units (poises or centipoises) as shown above. For example, consider the following typical Reynolds number calculation



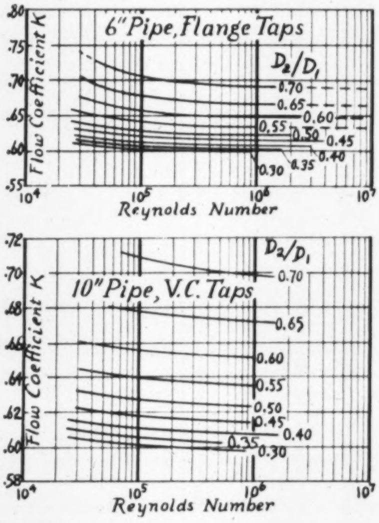


Fig. 8. Flow coefficients at low, "transition," and high Reynolds numbers.

when flow rate equals 50,000 lbs. of water per hour, orifice diameter equals 3.00 inches, and water temp. is 60 F. The absolute viscosity of water at 60 F. is 1.0 centipoise, or 0.01 poise.

First convert 1.0 centipoise to English units of viscosity:

$$0.01 \text{ poise times } 0.0672 \text{ equals } 0.000672 \text{ lb./ft.-sec.}$$

Therefore, Reynolds Number

$$R = \frac{0.00424 \times 50{,}000}{3.00 \times 0.000672} = 105{,}000$$

PIPE-LINE CONNECTIONS

Fig. 9 shows the five types of pressure connections used most often for orifice installations. Venturi tubes have built-in taps.

Pressure taps are referred to in many ways. Some of the names for pressure taps are: Inlet—outlet, upstream—downstream, high pressure (H.P.)—low pressure (L.P.), high—low, leading—trailing, static—throat, K1—K2, P1—P2, and F—S. These terms are self-explanatory. The first word or letter of the set is the first pressure tap reached by the fluid as it approaches the differential device. This first tap measures the static pressure of the line. The second tap measures a lower pressure. The two taps, together with the device (the primary element), comprise the metering installation in the pipe line.

The choice of pressure-tap location is influenced by (1) *flange thickness*, because vena-contracta and radius taps cannot be used if the downstream flange is too thick, (2) *pipe size*, because only corner taps are recommended for lines smaller than 1½ inch (a tee fitting has a turbulent effect on the flow in a small line), (3) *length of meter run*, because pipe taps require a longer length of straight pipe downstream than the others, (4) *coefficient data*, because reliable coefficients are not available on some taps for all conditions of pipe size, beta ratio, and Reynolds number (data are most plentiful on vena-contracta, flange, and pipe taps), and (5) *flowmeter range*, because if the maximum differential-pressure range of the flowmeter is limited, it may be better to use pipe taps, as they produce the lowest differential pressure for a given flow. Vena-contracta taps produce the highest differential for the same flow.

Flange taps are the most popular, mainly because the taps come ready-made in the flanges and no tapping of the pipe is required. They are suitable for all size pipe from 1½ inch up. Their only drawback is their expense compared to a standard pipe flange.

Pipe taps are used mostly in the fuel-gas industry because in gas measurement the differential must be small in relation to line pressure to avoid large corrections for compressibility. A good rule to follow in gas measurement is to keep the meter range (in inches of water) less than the gage-pressure upstream (in pounds per square inch).

Vena-contracta taps are used commonly in steam measurement because steam velocities and pressures are much higher than for gas, and the need for a low-range meter is not a factor as with the gas industry. The one great disadvantage of vena-contracta taps is that the exact location of the vena contracta varies with beta ratio. Thus, as one fixed set of taps is suitable for only a small range of beta ratios, there is not as much freedom of orifice exchange. Another disadvantage is that in small-size pipe lines the downstream spacing becomes so short that the flange thickness becomes a factor.

Radius taps, or throat taps, are a modification of the vena-contracta tap.

Corner taps have been used extensively in other countries, but have only recently come into broad use in the United States, mostly on small-size pipes (1½ inch and smaller). Their name stems from the manner of taking off the pressure in the corner formed by the pipe wall and the orifice. Little reliable coefficient data are available. They are not recommended for dirty fluids due to danger of stopping up the narrow passages.

Fig. 9 shows a typical flow pattern of a stream passing through a vena-contracta restriction. Note the location of the downstream tap. The flow pattern is similar for all orifices, nozzles, venturis, and other geometrically regular restrictions.

METER RUNS

The meter run is the length of straight pipe required upstream and downstream—that is, for the approach and outlet sections of a restriction. Fig. 10 shows the minimum recommended lengths of straight-pipe meter runs. The curves apply to all orifices, nozzles, and venturis. They are based on years of experimental research.

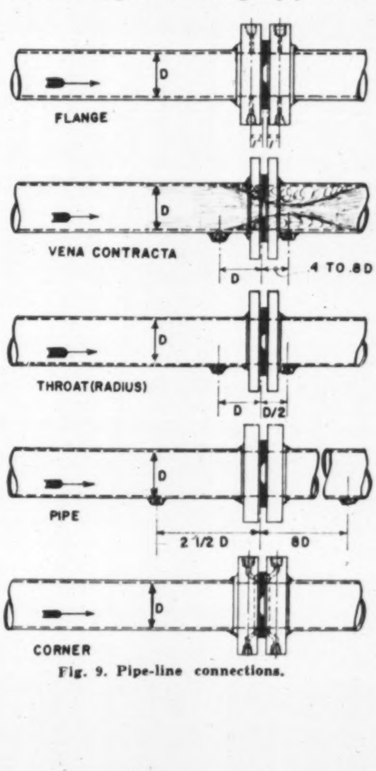


Fig. 9. Pipe-line connections.

If there is not sufficient meter run available, it is possible either to install *straightening vanes*, or to reduce the required diameter ratio of the primary element. The latter can be done by (1) increasing the differential head, (2) making the meter run of larger size pipe, (3) using a nozzle or venturi rather than an orifice, or (4) reducing the meter capacity.

Straightening vanes can be purchased from flowmeter manufacturers or made in the user's shop. Although there are various designs, a straightening vane is a nest or bundle of tubes or channels installed in the inlet section to eliminate swirling flow by forcing the stream to flow straight for several diameters of pipe. Vanes reduce the straight pipe required in the approach section of the meter run.

OTHER ORIFICE TYPES

The discussion heretofore has been based on *concentric* orifices, which have the hole concentric with the pipe. Concentric orifices are used most commonly because they are easiest to produce and more is known about them. However, orifices can be made with any geometric shape—square, triangular, clover-leaf, and so forth. There is no reason to make the hole circular and concentric except that it is easier. There are a few installations where it is desirable not to have the "dam" across the pipe line produced by the rim of the orifice, as in horizontal fluid-streams containing solid matter. In such applications an *eccentric* or *segmental* orifice, (Fig. 5) may be used with the edge of the orifice hole almost flush with the bottom of the pipe. Flow coefficients for these two types of orifices are not commonly publicized, although it will not produce great error to use coefficients for concentric orifices, provided that the pressure connections are made in the side of the pipe or flange and not in the top when the hole is made flush with the bottom of the pipe.

Orifice fittings are finding increasing use in the natural gas transmission industry. The one shown in Fig. 11 is known as a "senior fitting," in which type the orifice can be withdrawn from the pipe-line without shutting down the line. The less expensive "junior fitting," made without the built-in valve, requires that pressure be relieved from the line before the orifice may be removed for inspection or replacement.

ADJUSTABLE ORIFICES

An *adjustable orifice* is a special type of segmental orifice, like a specially shaped gate valve. It is used also in applications requiring frequent changes in meter capacity so that the line need not be shut down for orifice changes. However, this fitting must be individually calibrated, whereas the orifice fitting uses a standard concentric orifice with flange-top coefficients.

MAKING AND INSTALLING ORIFICES

First calculate the bore or, if the flow conditions are unknown, assume a figure for the bore. A machineable stainless steel is usually recommended for the material. The thickness is determined by the size of the pipe line—for up to 4-inch pipe the thickness should be 1/16 in. to ⅛ in., 5-inch to 14-inch pipe should be ⅛ in. to ¼ in., 16-inch pipe and larger pipe should be ¼ in. or more. The outer diameter of the plate should make a snug fit within the flange bolts; it usually is taken equal to the bolt-circle diameter minus the bolt size. A handle, or tab, is attached to the disk for a two-fold purpose—(1) to aid in inserting the plate between flanges and (2) to carry orifice data so it may be rechecked without having to shut down the line and remove the plate for measuring. This handle must be narrow enough to fit between two adjacent bolts, and long enough to protrude beyond the flange insulation so the data may easily be read. The handle may be an integral part of the plate or may be welded on after the plate is machined.

The finished hole must have the inlet edge sharp and square with the face of the plate, so that it will not appreciably reflect a beam of light. The orifice plate should meet the following flatness specification: "Any plate which when clamped between flanges does not depart from flatness along any diameter by more than 0.01 in. per inch of pipe radius shall be considered flat." The plate thickness at the metering edge should not exceed: (1) 1/30th of the nominal pipe diameter (D), or (2) ⅛ of the orifice or bore diameter (d), or (3) ¼ of the dam height (D−d)/2. When the outlet face of the plate is beveled, the handle should have the word INLET stamped on the square, or unbeveled, side.

The pipe walls in the vicinity of the orifice must be smooth, and the pressure openings through the pipe wall must be sharp. If flanges are welded on, the welding usually raises a "bump" around the inside, and weld "icicles" are sometimes formed. Any such bump, irregularity, or shoulder formed by the attachment of flanges must be removed. There must be no abrupt discontinuity or change of diameter near the orifice.

If pressure taps are made through the pipe wall, a half pipe coupling should be welded to the line at the proper point, then should be drilled by using the coupling as a jig or guide. A ¼-inch drill is satisfactory for all pipe sizes. When drilling the ¼-inch hole through the pipe wall, the burr which usually is formed when the drill breaks through the inner wall must be removed. When using ready-tapped orifice flanges the holes should be checked to assure that there are no irregularities around the edges.

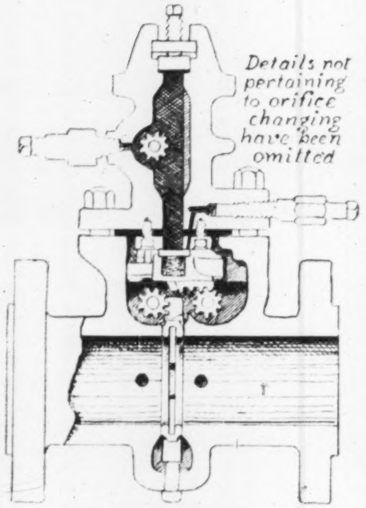
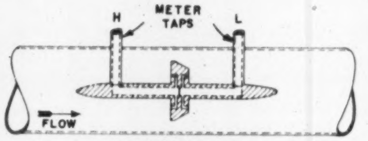

Details not pertaining to orifice changing have been omitted

Fig. 11. Orifice fitting.

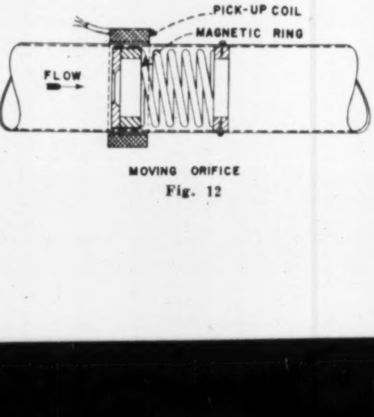
Gaskets are used on both sides of the orifice or nozzle flange when bolted between flanges, unless the joint has tongue-and-groove or ring-joint facing. These latter types require a special orifice design with regard to thickness and outer diameter, which is not discussed in this chapter.

ANNULAR AND MOVING ORIFICES

An *annular orifice* is a disk held fixed in the center of the pipe, leaving an annular space between the disk and the pipe wall for the fluid to pass through. The two pressure connections are made in the plate itself (integral taps), with tubing connections leading to the pipe wall. A *moving orifice* is one which is held in the pipe attached to a coil spring. The differential pressure across the orifice plate causes it to compress the spring. The axial movement of the plate is detected and measured either electrically by an induction coil formed around the pipe, or mechanically by means of a stuffing box connected to an external pointer and scale. Both of these types of orifices are rarely used and require individual calibration. An annular and a moving orifice are shown in Fig. 12.



ANNULAR ORIFICE



MOVING ORIFICE

Fig. 12

CENTRIFUGAL-TYPE HEAD METERS

It was previously mentioned that there is no reason for using an artificial flow restrictor such as an orifice to create differential pressure, except that individual calibration can be avoided by using tried and proven shapes of restrictors. In some situations even the small head loss created by the most efficient venturi tube can not be tolerated. In these situations engineers have resorted to taking the differential pressure across existing fittings and restrictions. Then by careful calibration the variation of differential pressure with flow changes can be plotted. This has been done across (1) elbow taps, with differential-pressure measurement taken on inner and outer radii of an ordinary pipe elbow, (2) hydraulic-turbine scroll-case taps (known as Winter-Kennedy taps), utilizing the drop in pressure between two points in the scroll-case, and (3) guide-vane speed-ring taps (known as Peck taps), a sort of hybrid pitot in which an impact opening in the leading edge and a static opening along the curved side of the vane comprise a pair of meter taps. The pressure differential in these devices is a result of a combination of centrifugal and velocity conversion.

MANOMETERS

The primary device translates fluid flow into a differential pressure. The device that measures the differential pressure is known as the *secondary element* of a flowmeter.

The instrument that measures the differential pressure is often called the "flowmeter," although the instrument itself cannot be a complete flowmeter. It cannot give flow readings without being connected to the pipe-line device. A complete flowmeter consists of a combination of elements that respond to flow rate and produce flow rate readings.

Secondary elements are essentially manometers, or pressure-measuring instruments. A pair of ordinary Bourdon-type pressure gages would work except the accuracy of such gages is usually not high enough. The reader is referred to Chapter VII for a more thorough discussion of all types of differential pressure measuring instruments.

SQUARE-ROOT EXTRACTION

A major item in flowmeter design is the means for extracting the square root of the differential head. Flow rate varies as the square root of the differential head. If the secondary element does not extract this square-root function, the pointer or pen shows head changes only, in which case the dial or chart on the instrument reads differential pressure and not flow rate.

Many users of flowmeters prefer to use direct-reading dials or charts which are marked in flow rate rather than differential head. This can be done simply by marking each scale unit of differential pressure with its corresponding flow rate. The scale markings or divisions in this case are not uniformly spaced. Such a scale is known as a square-root scale. It is characterized by the fact that the spacing between equal flow increments is shorter at the lower end of the scale (near zero) and spreads out at the upper end.

Some flowmeter users prefer to have uniformly-spaced dials and charts. For this group of users some flowmeter manufacturers have provided methods in the mechanism for extracting the square-root. The methods used fall into two broad categories—shaped manometer parts, and cams.

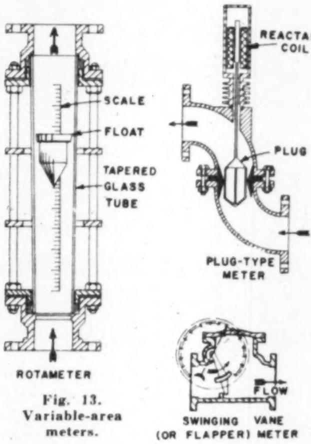


Fig. 13. Variable-area meters.

Variable-area Meters

The rotameter.—The rotameter is second in importance to the variable-head meter in industry. All rotameters are basically alike in principle of operation. In theory the rotameter is very similar to a head meter. It consists of a float or moving element of constant weight and area, which is free to move vertically in a tapered tube of glass or metal, smaller at the lower end. The flow is directed upward through the tapered tube. The float finds a position in the tube where its buoyancy is exactly balanced by the combined forces of differential pressure across the float, and viscous drag of the fluid flowing around it.

The term "rotameter" stems from the earliest types of variable-area flowmeters, in which the float always rotated. A spinning float is more stable and hence easier to read. Further, the spinning motion keeps the float clean. However, technological improvements in rotameter design have made it unnecessary for the float to rotate in some applications.

Fig. 13 illustrates a simple type of rotameter. As the annular area between float and tube wall is momentarily fixed, the differential pressure across the annular orifice must increase when the flow rate increases. As the float buoyancy is constant, the increased differential head overcomes gravity, and the float moves upward to a larger annular area, which reduces the velocity to the point where gravity again balances differential pressure exactly.

The rate of flow is either marked on a scale attached to the tube or etched on the glass tube itself; the position of the float in the tube gives the flow rate. The rotameter must be calibrated or, as with head meters, a relationship must be set up between float characteristics, tube size, and flow rate.

The *advantages of rotameters* are (1) they handle corrosive fluids, (2) the visible float is a constant check on operation of the meter and on the condition of the fluid, (3) they have uniform accuracy at all flow rates when properly calibrated, (4) they have uniform flow graduations without square-root extraction complications, (5) the pressure loss is fixed at all flow rates, (6) their capacity is easily changed by replacing float or tube, and (7) they do not require a meter run.

The *disadvantages of rotameters* are (1) the piping installation is usually more complicated than for a head meter, (2) they are limited as to working pressure and temperature without expensive designs, (3) they are expensive in large pipe sizes, (4) the glass tube is fragile and easily broken when installing or when, after installation, it is subjected to mechanical or thermal shock, (5) under some conditions they require frequent cleaning, and (6) they present packing problems under some conditions.

Other Variable-area Flowmeters

Although the rotameter is the most popular type of variable head meter, Fig. 13 shows two other types in use today—the swinging-vane type and the plug type.

The swinging-vane meter is a device similar to an ordinary swing-check valve which is specially calibrated to give flow readings corresponding to vane position. The plug-type meter is similar to a rotameter in that upward movement of the plug results in more area for passing the flow.

Rotating-member Meters

A rotating-member meter is a flowmeter that uses a propeller-like rotating member to average pipe-line velocity. Such meters, which have been used for many years in measuring air flow, are known as *anemometers.* Each meter must be calibrated in the fluid in which it will be used, but once calibrated, an identical duplicate meter can be used without individual calibration. The rotational speed of the runner may be translated into rate-of-flow readings by ordinary tachometer type devices. One type of rotating member meter is shown in Fig 14.

Turbine-type Primary Elements

Flow-rate measuring systems employing a turbine (or propeller) type of primary element are gaining recognition in some fields. Originally developed for military uses (aircraft and missiles), this type is available at this writing in two designs: in small sizes with end connections for flared tubing as in Fig. 15, and in large sizes for mounting in a conventional pipe flange.

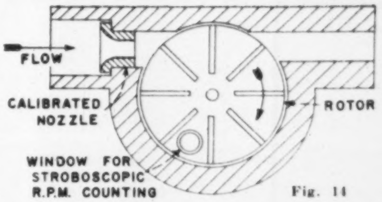


Fig. 14

The absolute accuracy of this element is, like that of any orifice, nozzle, or Venturi, no better than the accuracy of its manufacture and calibration. Unlike these, however, the turbine-type element should be individually calibrated to justify its use. This procedure adds extra cost to a device which is more expensive than the usual primary element without moving parts. Once calibrated, however, it will repeat to a high degree. Under favorable conditions, a repeatability of 0.1 percent is possible; in ordinary use one can expect 0.5 to 1 percent. Thorough calibration is essential. To calibrate, water is usually flowed through the element and weighed. This hydraulic calibration is then valid for any other liquid (not gas), after correcting for specific gravity and, when necessary, shrinkage or expansion of the housing due to thermal departure from calibration temperature. This type of element is not usually recommended for gas service.

The principle of operation is analogous to that of an a-c. generator. Either one of two methods may be employed. In the Fig. 15 device, a stationary permanent magnet is contained within a pickup coil mounted on the outside pipe wall. The flux field produced by the magnet is cut by the ferromagnetic blades, generating a series of electric pulses. In another type the permanent magnet may be imbedded either in the turbine hub or in the blade tips, rather than in the coil. In this type the flux field moves as the turbine rotates and cuts the coil, generating either an a-c. sine-wave or a series of pulses.

In both types, the frequency of the

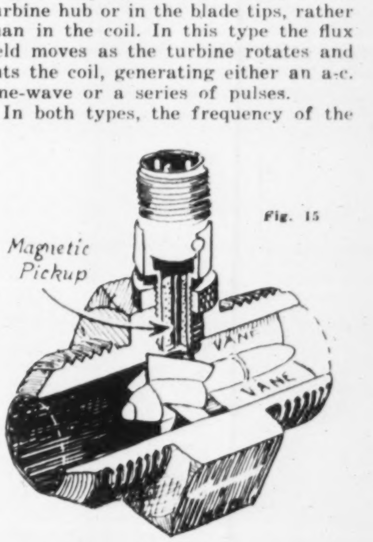


Fig. 15

a-c. signal is directly proportional to the rate of flow. The frequency may be intentionally varied from one element to another by changing the pitch of the blades, by using multipole magnets in the hub, by not activating all the blades, or by combinations of these methods. The pipe, of course, must be of non-magnetic material.

To complete the flow-measuring system, one needs only an accurate frequency meter, a pulse-counter, or an FM/DC converter with a d-c. millivoltmeter. For highest accuracy, the best choice of read-out would be the "EPUT" (event-per-unit-time) form of pulse counter, or a record of the wave-form on a photographic or stylus-type oscillograph.

A disadvantage in this type of flowmeter, aside from its purchase cost and individual calibration, is bearing trouble due to erosive and/or corrosive fluids. Overspeeding the turbine without excessive gas flow is to be watched although the type illustrated has been found to be less susceptible in this respect than earlier designs.

In recent years a spinning-ball flowmeter has been developed in which a channel or raceway is circumferentially machined in a pipe-line fitting. A ball is caused to spin around the periphery of this raceway by the fluid stream because all the flow is diverted through the raceway. An induction-coil pickup on the outer diameter of the fitting generates an electrical signal with each passage of the ball. These signals are electrically timed and integrated to produce a modulated direct current, the value of which is directly proportional to the rotational velocity of the ball. The disadvantages of this type of rotating-member meter are (1) the ball wears rapidly under certain conditions, and (2) the meter must be often recalibrated. Owing to their low bulk and ready adaptation to electrical circuits, rotating-member flowmeters are popular in aircraft work for flight testing.

ELECTRICAL TYPES

An electrical type of flowmeter is not one that uses electrical transmission of intelligence obtained with the usual mechanical-type head meter. It is one in which the velocity is sensed electrically. Four basic types are (1) the thermal meter, (2) the hot-wire anemometer, (3) the electromagnetic meter, and (4) the sonic flowmeter.

A *thermal-type flowmeter* measures velocity by electrically heating the fluid stream. This may be done either by adding a constant electrical power (hence a constant B.T.U. or calory input) and measuring the temperature rise of the fluid, or by adding a varying power to maintain a constant temperature rise. Neither method has proved very popular in the gas industry, where it has been used most frequently, because of the cost of electric power and the large errors inherent in temperature measurement. However, the advantage of thermal-type flowmeters over head meters is that the accuracy of the former is not much affected by changes in gas density.

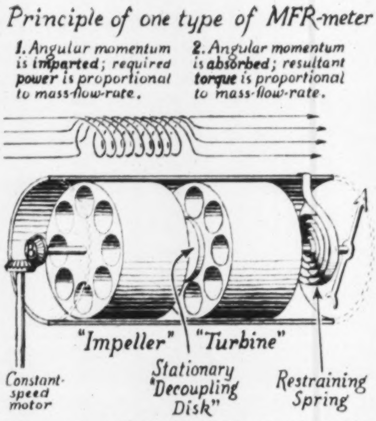

Principle of one type of MFR-meter
1. Angular momentum is imparted; required power is proportional to mass-flow-rate.
2. Angular momentum is absorbed; resultant torque is proportional to mass-flow-rate.
"Impeller"
"Turbine"
Constant-speed motor
Stationary "Decoupling Disk"
Restraining Spring

Fig. 16. NOTE—Function of "decoupling disk" is to prevent "hydraulic-transmission" effect at zero or low flow-rate.

A *hot-wire* anemometer operates by measuring the amount of current required to maintain a resistance coil in the fluid stream at constant temperature. It is similar to the thermal-type flowmeter and has the same advantages and disadvantages.

An *electromagnetic meter* measures fluid velocity by (1) imposing a magnetic field across the stream, which must be a fluid of suitable magnetic susceptibility, and (2) measuring the d-c. potential generated in the fluid at ninety degrees from the magnetic poles that impose the field. The advantage of this type meter is that the signal is directly proportional to flow. This eliminates the necessity for square-root extraction, which is needed in other-type flowmeters in order to obtain a linear flow-rate scale.

The *Sonic Flowmeter*, another recent development in electrical types, bears watching because, like the electromagnetic type, there are no parts in the stream to cause trouble. This element's principle is based on the velocity of sound: A high-frequency signal is passed across the flowing stream in a pipe-line in two directions: upstream and downstream. The difference in time required for the two signals to travel the same distance with the flow and against the flow, is a measure of the average fluid velocity in the pipe. Certain restrictions in fluids, pipe sizes, pipe materials, etc. are being evaluated and, until this work is more nearly complete, there will be little to expect in commercial products.

MASS FLOWMETERS

All of the foregoing discussion relates to *volumetric* rather than *gravimetric* measurement of flow-rate. Velocity in the pipe-line is gaged, and the flowmeter reads volume (cubic feet, gallons, etc.). If the density or specific gravity remains constant, simple arithmetic converts the flowmeter scale readings to gravimetric or weight units (pounds, etc.). If the density varies, as it usually does, we have to correct for it.

This problem has led to the recent development of *mass flowmeters* reading in pounds of mass regardless of volume. One promising type utilizes the principle of "Coriolis acceleration," following Newton's second law of motion: If a fluid passing through a pipe-line is acted upon so as to give it a velocity at right angles to the main flow, and if this angular velocity is then measured in terms of the torque ("twist") imparted to a set of vanes, the torque measurement will be closely related to the mass flow.

Fig. 16 illustrates a type of mass flowmeter in use today. A constant-speed motor drives an impeller similar to a centrifugal pump. This imparts an angular velocity to the stream. Immediately following the impeller is a set of turbine blades, against which the flow is directed. The turbine blades tend to rotate but are restrained by a control spring. The deflection can then be calibrated in terms of mass flow: pounds per hour, etc.

In another type (not illustrated) the torque measurement is the phase difference between the rotating case and a fixed set of vanes built into the same case.

High accuracies and repeatabilities are attributed to these devices, which, coupled with the advantage of density and viscosity immunity, tend to overshadow the disadvantage of a rotating shaft with its problem of seals. It can also be seen that frequent cleaning would be necessary in some uses. At this writing, military needs are claiming all of the production.

Other mass flowmeter designs are based on a volumetric flow measurement with a built-in density correction. One commercial instrument employs a turbine-type primary element. A sample of the liquid passing through this element is diverted through a density-sampler. The density measurement electrically compensates the pulse signals coming from the turbine element.

AUTOMATIC CONTROL OF FLOW-RATE

Process control is treated in Chapter XIII which describes the principal modes of control, and their effects both singly and combined.

However, Chapter XV takes temperature control as the specific example. With respect to automatic control of flow-rate, the most important point to bear in mind is that the "rate" or derivative mode of control worsens instability—especially when nearly-incompressible liquids are to be controlled. An excellent mode of control is the *inverse derivative* (formerly available from only one instrument company but since 1953 available from numerous licensees). This mode consists in automatic *widening* of the proportional band in proportion to the time rate of deviation from the set point.

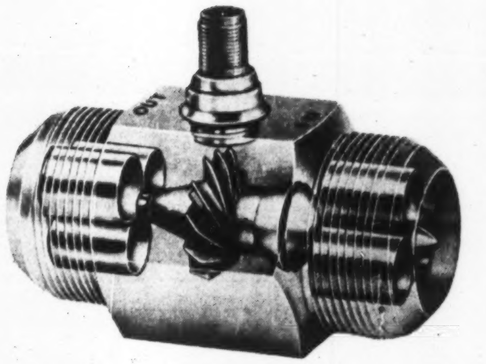
Another point of difference is that flow-rate can be controlled precisely by means of metering pumps (adjustable positive-displacement pumps).

POTTER AERONAUTICAL COMPANY

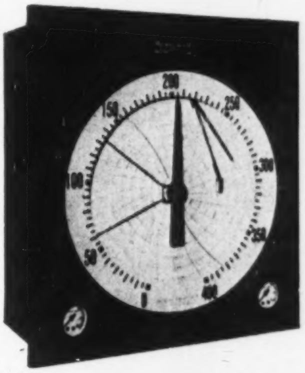
Route 22, Union, N. J.

PRECISION FLOW METERS AND CONTROLLERS

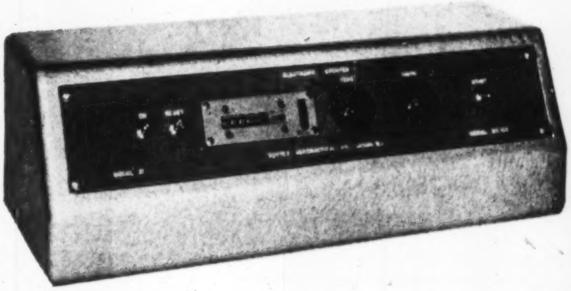
FOR ALL TYPES OF FLUIDS INCLUDING ACIDS AND CAUSTICS, HIGH PRESSURES, HIGH TEMPERATURES



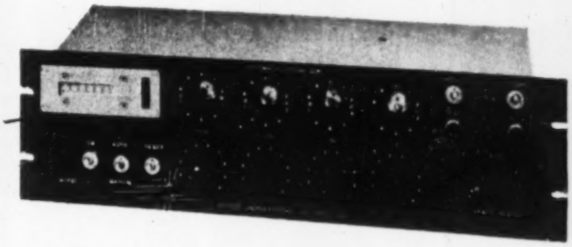
THE POTTER FLOW SENSING ELEMENT, able to withstand temperatures from -450 to +1200 degrees F, and pressures in excess of 35,000 psi has brought a new standard of accuracy to industrial flow measurement. The sensing element is linear within 1/2% of instantaneous flow; repeatable within 1/10% at any given point.



RECORD, INDICATE RATE OR RATIO with high accuracy even under difficult conditions. Linear flow indicating or recording systems are accurate within 1/2%; control with comparable precision. Ratios can be as high as 1000-to-1.



MEASURE TOTAL with accuracies as high as 1/10% using an instrument only three inches high, nineteen inches wide. The Potter Totalizer, designed for mounting in a standard relay rack, can be used in conjunction with Potter rate measuring systems.



CONTROL BATCHES AUTOMATICALLY. Potter batch control systems are accurate within 1/5% or better; can be designed for sequence operation to blend a number of ingredients for low-cost automatic batching. Human error is easily eliminated in product mixing.

FIND OUT how Potter Flow Meters fit into your processes to improve metering accuracy, save time, and aid in product control and cost accounting. Write for information on: Industrial Flow Meters, Laboratory Flow Meters, Automatic Batch Control.

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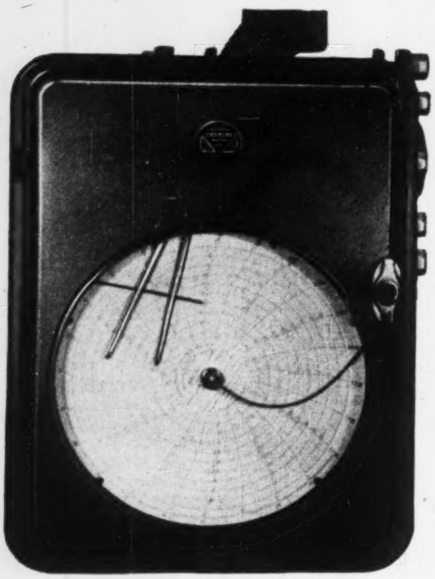
AMERICAN® ORIFICE METERS

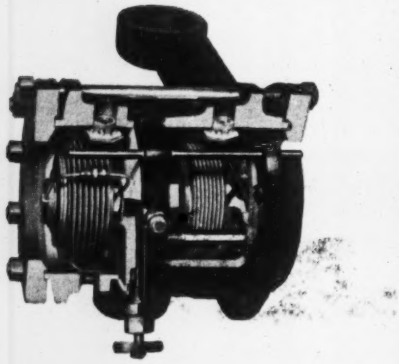


- ***RECORDING***
- ***INTEGRATING***
- ***INDICATING***

Your specific requirements for accuracy, simplicity and dependability in differential pressure measurement will be met with one of two basic American Orifice Meters—the *American Dri-Flo* and the American Westcott Mercury Manometer. Recorders are available with square root or direct reading charts. Integrating meters totalize fluid quantities, integrating static and differential pressures. Indicating instruments show rate of flow where records are not required.

CANNON METER PENS

Stainless steel non-clogging Cannon pens reduce meter inking problems to the minimum. Ink flows upward by capillary action from a half-ounce reservoir holding and protecting a year's supply of ink. The instruments are unaffected by pulsating flows, rapid pen movement or atmospheric fluctuations. Available in various styles for all standard recording instruments.



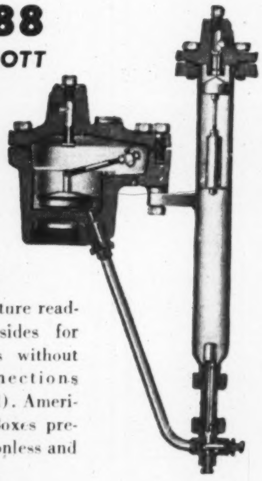
AMERICAN DRI-FLO

MERCURYLESS ORIFICE METERS

These new instruments provide *American Westcott* precision accuracy for applications where mercury manometers are not desired. Available in 50", 100" and 200" ranges, working pressures to 1000 P.S.I., ambient temperatures of −25° to 175°F.

SERIES A-88

AMERICAN WESTCOTT MERCURY MANOMETERS



For working pressures of 1800, 3000 and 5000 P.S.I., these basic instruments feature readily interchangeable high-sides for differential range changes without disturbing gage line connections (1800 P.S.I. unit illustrated). American Teflon Seal Stuffing Boxes prevent leaks, are nearly frictionless and do not require lubrication.

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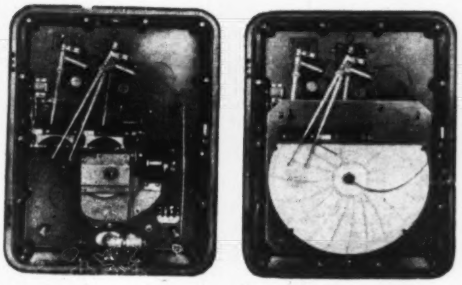
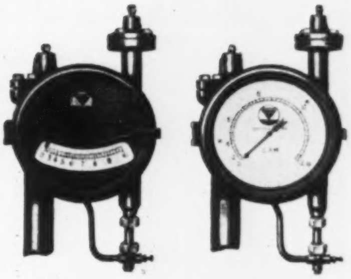
AMERICAN PRECISION INSTRUMENTS



INTEGRATING METERS

Standard American Westcott Orifice Meters equipped with integrating mechanisms provide totalized readings of the fluid quantities passing through the measuring orifice for all rates of flow or variations in pressure. The instruments integrate for static pressure and differential pressure.



INDICATING METERS

American Westcott Indicating Meters are adaptations of standard American Westcott Orifice Meters for use where permanent records are not required. The rate of flow of air, gas, oil, steam or water are indicated on the dials of the instruments. Meters are available with Round Dials having pointers which move through 270 degrees or with Segmental Dials with pointers moving through 45 degrees.

BASE PRESSURE INDEXES

For use with Ironcase Displacement Meters, these units automatically multiply the quantity of gas passing through the displacement meter, at pipe line conditions, by the factor of the line pressure divided by the base pressure. The totalized readings are continuously registered on a straight reading index.

BASE VOLUME INDEXES

Metric Base Volume Indexes register the total quantity of gas passing through the Ironcase Displacement Meter in cubic feet under standard conditions of base temperature and base pressure. Each cubic foot (actual volume at line pressure) is multiplied by the factor for flowing temperature, and this product is subsequently multiplied by the factor for line pressure.

VOLUME AND PRESSURE GAGES

Installed on Base Pressure, Base Volume or ordinary Indexes, these instruments chart the time and pressure at which each 1000 cubic feet of gas passes through a displacement meter for a permanent hourly record of load conditions.

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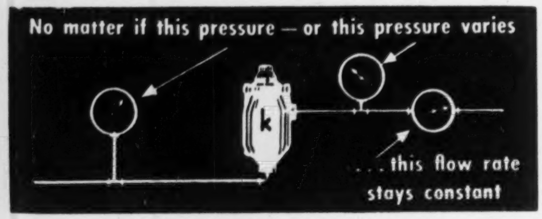
CUT PROCESSING COSTS . . .
And INCREASE PRODUCTION


No matter if this pressure — or this pressure varies
k
. . . this flow rate stays constant

. . . BY CONTROLLING LIQUID FLOW THIS SIMPLE WAY with a

Kates Regulator

The installation of a Kates Regulator in the inlet line to a filter . . . to an oil burner nozzle . . . to a deionizer . . . or behind any centrifugal pump, almost instantly results in lower product handling costs and far greater production.

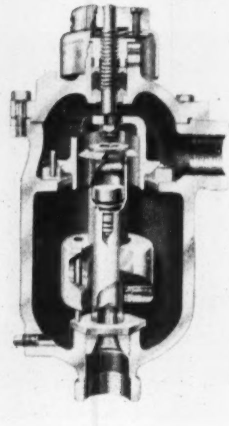
A Kates Regulator smooths out the "ups and downs" in flow rate that occur in almost every liquid handling process. *It is vital in filter pre-coating because it helps to build up a smooth, uniformly dense filter cake—thus assuring longer filtration cycles, finer quality filtration, less costly down-time and greatly reduced filter and requirements. *It is vital in the control of regeneration, backwash or rinse rates where undesirable surges of liquid flow can produce "channeling" or the loss of costly ion-exchange resins. *It is vital in controlling the flow of fuel to a burner where surges of liquid can cause clogging of the nozzle and unnecessary, wasteful distribution of fuel which cannot be efficiently consumed.

In hundreds of other applications, such as blending and proportioning, solvent extraction, chemical process control, diluting of bulk heavy chemicals and evaporator influx a Kates Regulator performs an outstanding, dependable job—simply, accurately, and at low cost.

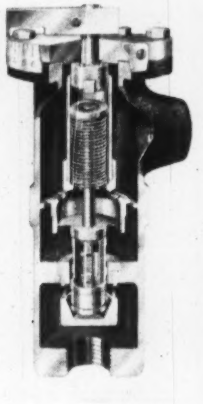
And, when used behind a centrifugal pump, a Kates Regulator provides proportioning control equal to that of much more costly equipment. Learn how adaptable Kates Regulators can be fitted into your liquid control systems—to save you money and do the kind of control job you **want** done.

Contact Your Local Representative or Write Today for Complete Information and Technical Data.

2 Types of Kates Regulators



TYPE GA
for Clear Liquids



TYPE SA
for Liquids and Light Slurries

. . . and how they work:

Both the Type GA and Type SA regulators are simple, self-contained units that are extremely rugged in design. Installed in liquid-handling lines, the Regulators automatically compensate for fluctuation in either their inlet or outlet pressures. A direct-acting valve within the Regulator **automatically** opens or closes to adjust the flow to the pressure change. Thus, the flow of liquid out of the regulator is always smooth and unvarying from the set rate.

TYPE GA

Size	Flow Rating in GPM of Water	Dimensions Pipe Conn.	Approximate Dia.	Approximate Height
0-GA	0.05-0.50,0.10-1.00,0.10-1.50, 0.10-2.00	½"	4¼"	11¼"
2-GA	0.50-6.50, 1.00-12.50	1 "	5¾"	11½"
4-GA	2.00-20.00, 4.00-40.00	1½"	6½"	14½"
5-GA	5.00-50.00, 10.00-100.00	2 "	9½"	19 "

TYPE SA

Size	Flow Rating in GPM of Water	Pipe Connection	Approximate Dia.	Dimensions Height
1 SA	2-10	¾"	3½"	9 "
2 SA	4-20	1 "	4½"	11½"
4 SA	10-50	1½"	6 "	14 "
5 SA	20-100	2 "	8½"	19 "
6 SA	35-175	2½"	9½"	21 "
7 SA	50-275	3 "	10 "	23 "
8 SA	100-550	4 "	13 "	30 "

Standard regulators will hold set point flow within ± 3% for pressure variations up to 125 psi.

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Republic

PNEUMATIC TRANSMITTERS

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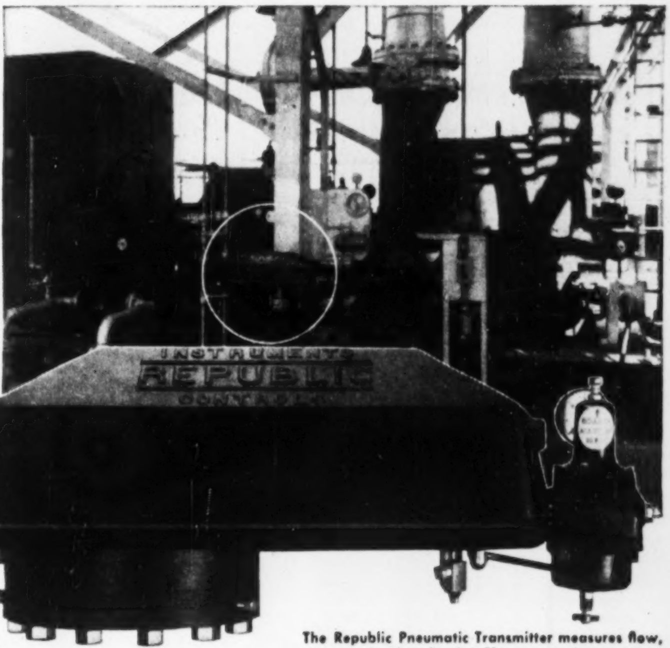
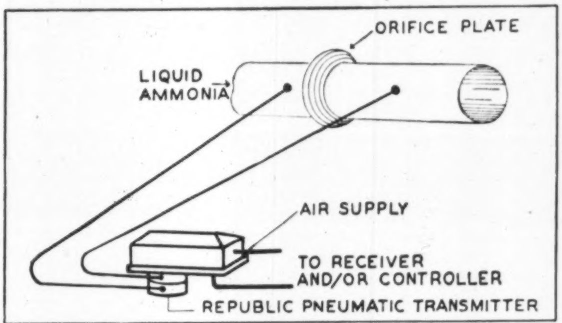
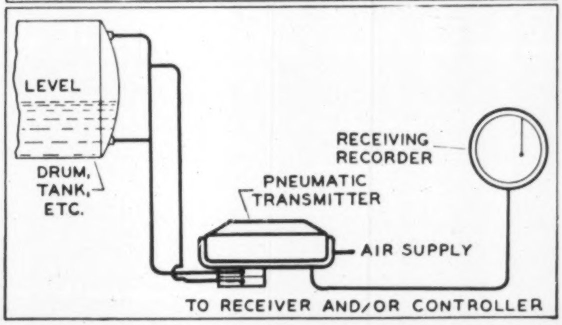


The Republic Pneumatic Transmitter measures flow, pressure, level or density. The pneumatic output can be used to operate reading instruments and as the measuring impulse to an automatic controller.

LOW DIFFERENTIAL FLOW MEASUREMENT

When pressure drops in flow lines must be kept small—as in the discharge of blowers—low range Republic Transmitters offer the most practical answer to flow measurement. For *only* with Republic Transmitters can you get differential ranges as low as 0-0.6-in. H_2O at static pressures to 15 psi and 0-2.5-in. H_2O at pressures to 1000 psi. This low range feature permits the use of devices producing a minimum differential; accurate force-balance measurement and control is possible with back-pressure on blowers, for example, held to a negligible figure.





METERING VAPOROUS LIQUIDS

Repulic's low ranges provide the key to successful measurement of easily vaporized liquids, too. Take the flow of liquid ammonia through an orifice as an example. By using an orifice producing a small differential drop, you avoid flashing the liquid into gas and getting an inaccurate measurement. And since the Republic Transmitter is a force-balance instrument, there are no problems of liquid seals, purging or overrange blowing the sealing liquid into flow lines.

LIQUID LEVEL MEASUREMENTS UNDER PRESSURE

This job requires an instrument with a narrow range span and considerable range suppression. High pressure, low range Republic Transmitters are available for just this kind of measurement. For accuracy and close control, range suppressions up to four times the range span are possible i.e., a Republic Transmitter with a 0-100-in. H_2O range can be suppressed to operate between any 20-in. H_2O span within the full 100-in. range.

● ***IF YOU HAVE A PROBLEM***

involving the measurement of FLOW, PRESSURE, LEVEL OR DENSITY with pneumatic transmitters . . .

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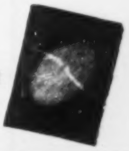

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WITH THE EXCLUSIVE STEP-VALVE DESIGN

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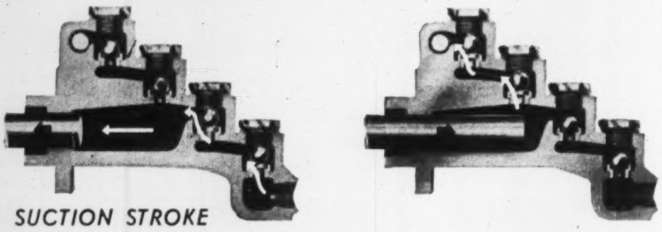
APPLICATIONS:

Milton Roy Controlled Volume Pumps are manufactured in a broad range of models and capacities to satisfy practically all control requirements—for automatic concentration control by means of continuous titration, and as components of complete instrumentation programs.

Milton Roy Pumps have application in continuous processing and chemical feed systems, including boiler feedwater treatment systems; for automatic pH control; for control by flow, electrical conductivity, temperature, pressure, liquid level, or other metered variables.

EXCLUSIVE LIQUID END STEP-VALVE



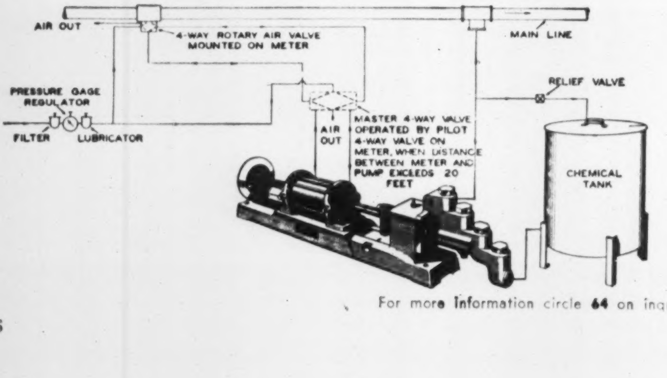
Milton Roy Controlled Volume Pumps employ the patented liquid end double ball-check step-valve, which is snap-acting, self-cleaning, and non-clogging . . . assures high and reproducible volumetric efficiency.

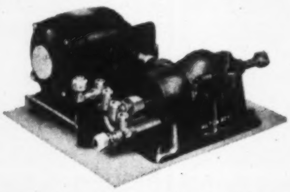
MILTON ROY PROPORTIONAL FEED SYSTEM

In proportional feed systems, a positive displacement meter in the main line operates a rotary air valve. Air impulses from this rotary valve control the rate of operation of a master 4-way air control valve which admits air alternately to opposite ends of the air cylinder, operating the pump. Any variation in the main line flow results in a proportional variation in the pump stroke rate. Since the capacity of the pump is a direct function of the stroke rate, pump capacity is exactly proportional to the main line flow. The ratio of pump capacity to main line flow may be varied as desired, by adjustment of the plunger stroke length while the pump is operating.

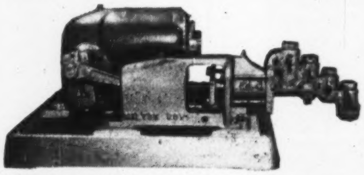
Timed electrical impulses to a solenoid-operated 4-way air valve may be substituted for the rotary-valve-master-air-valve combination.

In these proportional feed systems several "aiROYmetric" Pumps may be paced by the main line flow . . . each with independent capacity adjustment. This permits the precise ratioing of several streams to the same main line flow.

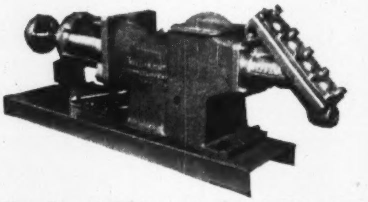

AIR OUT
4-WAY ROTARY AIR VALVE MOUNTED ON METER
MAIN LINE
PRESSURE GAGE
REGULATOR
FILTER
LUBRICATOR
RELIEF VALVE
AIR OUT
MASTER 4-WAY VALVE OPERATED BY PILOT 4-WAY VALVE ON METER, WHEN DISTANCE BETWEEN METER AND PUMP EXCEEDS 20 FEET
CHEMICAL TANK



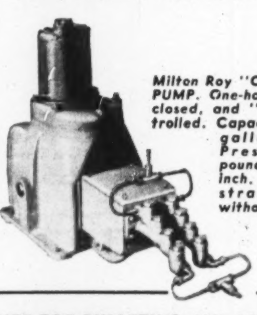
Milton Roy "miniPump". Capacity 3 to 3200 milliliters per hour. Pressures: Up to 1000 pounds per square inch. Application: metering of clear liquids. Available also in air-powered models, Simplex, Duplex, Multiplex, and "Constametric".



Milton Roy SIMPLEX PUMP. Fractional hp motor. Capacity: .1 to 340 gallons per hour. Pressures: Up to 5000 pounds per square inch.



Milton Roy "aiROYmetric" Model 1AC. Air-Powered. Capacity: .04 to 405 gallons per hour. Pressures: to 25,000 pounds per square inch.



Milton Roy "CONSTAMETRIC" PUMP. One-half hp motor, enclosed, and "Thymotrol" controlled. Capacities: .08 to 69 gallons per hour. Pressures: to 4500 pounds per square inch. Application: straight line flow without pulsation.

WRITE FOR BULLETINS: NO. 1053 AIR-POWERED CONTROLLED VOLUME PUMPS; NO. 553 MOTOR-DRIVEN CONTROLLED VOLUME PUMPS; NO. 653 "miniPump"

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Operation and Care of Circular-scale Instruments

By

JAMES SPENCER

For 20 years in charge of Instrument and Relay Department, Meter Div., Westinghouse Electric Corp.

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Barton sales representatives are always ready to help solve your metering problem. They can show you why Barton flowmeters require no specially trained personnel and require practically no service.

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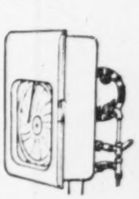
Differential pressure ranges from 20" WC to 400" WC. Pressures to 4500 psi. Static pressure pen is optional.



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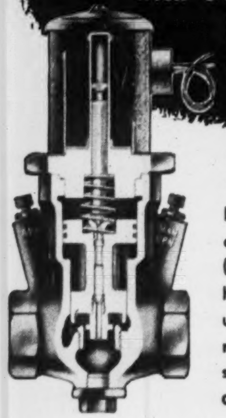

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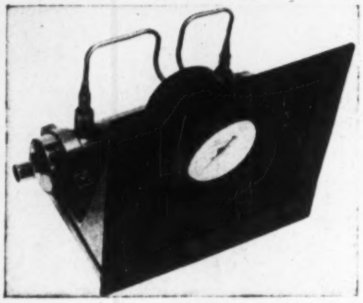

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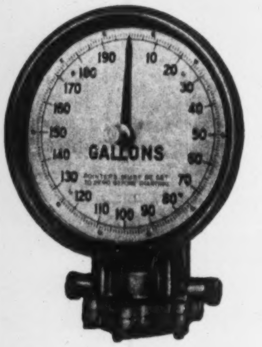

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CHAPTER VI

INSTRUMENTATION FOR CHEMICAL ANALYSIS AND CONTROL

[Author now with a company which forbids by-lines]

I. Introductory Notes

INSTRUMENTS of the type discussed in this Chapter are popularly referred to as *analysis* instruments or *concentration* instruments to designate their function in chemical process instrumentation. Their ultimate purpose is to measure chemical concentration and/or identify molecular species.

A precise definition does not permit a common and interchangeable classification of *concentration* instruments and *analysis* instruments, particularly as applies to chemical process control. Instruments which analyze by direct measurement are one means to the end of concentration control, but it can be shown that non-analyzing instruments are also applicable to chemical concentration by virtue of their use to maintain equilibrium conditions within a processing vessel as required by kinetics of chemical reactions. As for example, a simple flowmeter which regulates feed to a reactor becomes a non-analyzing concentration controller because the laws of Reactor residence and kinetics of chemical reactions express a fixed time relationship between effluent concentration and influent feed rate. It follows, therefore, that *analysis* instruments *per se* are but one type of concentration instrument; the broader term "concentration instrument" may be sub-divided:

(a) Analysis Instruments

(b) Non-analyzing Concentration Controllers.

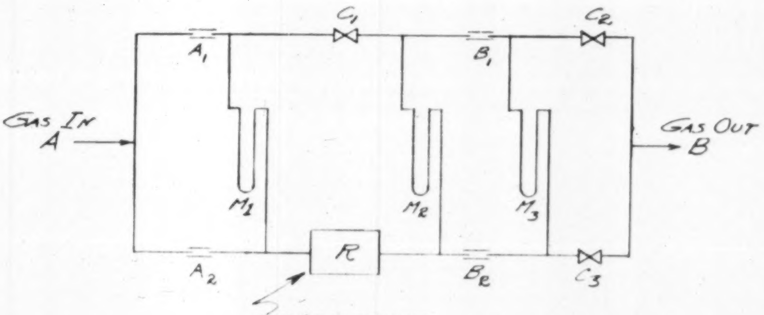

Fig. 1. Pressure-bridge principle of absorption analysis instruments for gas analysis. Pressure difference at M_3 and M_2 is proportional to absorption in R when pressure difference at M_1 is zero.

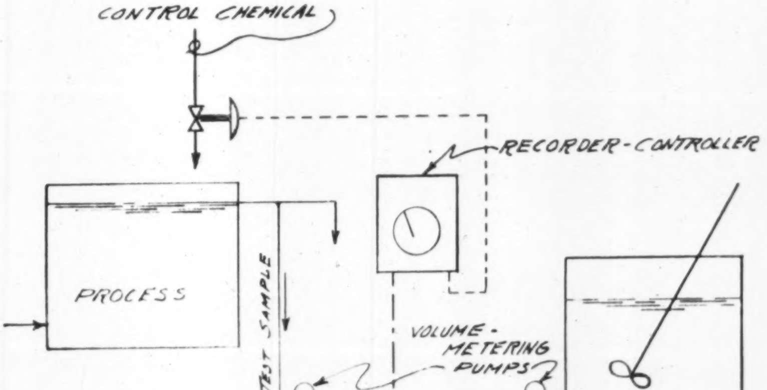

Fig. 2. Volume metering pumps deliver constant proportional volumes of reagent and process liquor to electrodes. Controller feeds control chemical to process to maintain optimum concentration. (See U. S. Patent 1,684,645).

Analysis instruments, as applied in industrial plant chemical processing, fall into two general categories pertaining to characteristic properties of the material measured. This general classification may be termed the MATERIAL PROPERTIES CLASSIFICATION. Further sub-classifications define the type of instruments, i.e., the principle of operations and the manner in which they are applied in measurement and control. Limitations of application and complexities of instrument types, and the degree of reliability and requirements for maintenance attention reflect with sharp contrast the various instruments which constitute the two general branches of the "Material Properties Classification."

Industrial analysis instruments evolve from methods based on:

(a) Chemical Properties

(b) Physical Properties

of the material measured. They may therefore, be classified respectively, as:

(a) Class "A" Instruments

(b) Class "B" Instruments

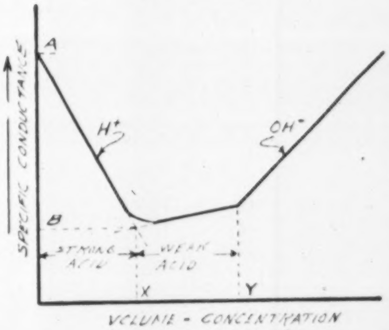

Fig. 3. Conductimetric titration characteristic of mixed weak and strong acids with strong base.

A wide variety of instrument types have been developed, but all are constituent members of either branch of the MATERIAL PROPERTIES CLASSIFICATION, and all may be indexed as Class "A" or Class "B" instruments. They analyze qualitatively or quantitatively by virtue of direct or indirect measurement of a chemical property or physical property of the material sought.

Instruments in both categories are dependent upon the chemical nature of the process material to which they are applied, and, for the most part, require specific design treatment and individual application engineering. Technical personnel must thoroughly analyze each process application to ascertain what outstanding property may serve to identify the material sought, and to determine what interferences will be encountered. A theoretical analysis leads to the selection of a preferred type of instrument, but it usually must be experimentally calibrated for, and adapted to, specific conditions of the application. A change of conditions of application may require re-adaptation of the instrument.

TABLE A-1—NON-REVERSIBLE CHEMISORPTION INSTRUMENTS

Method	*Measured Effect*	*Application*	*Range*	*Accuracy*	*Remarks*
Automatic Orsat	Change of volume of gas sample at constant pressure before and after absorption in chemical reagents.	Generally, analysis of acid-forming gases viz. SO_2, CO_2, CO, etc.	0-100%	Basic Orsat principle, 0.2% of theoretical. Industrial automatic instruments, 0.5%-10% of range.	Operates on discontinuous batch sampling at 2 to 3 minute cycle rate. Uses liquid chemical absorption reagent selective to the gas analyzed. Reagent becomes spent and must be replaced.
Pressure Bridge	Pressure loss in series orifices or pressure bridge as a result of chemical absorption. See Fig. 1.	Ditto above.	0-50%	0.5%-10% of range.	Operates on continuous flow gas sample. Generally uses dry absorbing reagent. Reagent becomes spent and must be replaced.

TABLE A-2—REVERSIBLE CHEMISORPTION INSTRUMENTS

Instruments of the types described in Table A-1 employ non-reversible absorbents. The reagent becomes changed in chemical composition by the gas sample and must be replaced. Reversible absorbents behave as catalysts and establish equilibrium with gas concentration and some physical property of the absorbent. They do not become "spent" except by "poisoning."

Method	*Measured Effect*	*Application*	*Range*	*Accuracy*	*Remarks*
Catalytic Oxidation—Reduction.	Electrical resistance of sponge silver catalyst planted on glass wool contained in analysis cell.	Oxygen Analysis.	Not established	Not established	Sensitive to small concentrations of O_2.
Catalytic Combustion.	Temperature rise of catalyst, viz. Hopcalite or silver permanganate contained in gas analysis cell.	Analysis of gases which undergo catalytic combustion viz. CO, NH_3, etc.	Trace quantities and low concentrations below 0.1%.	0.005% in range of 0.01%:5 ppm. (accuracy) in range 10 ppm. to 200 ppm. CO, or 2% theoretical O_2 in range 0.001%-to 0.2%.	Applicable to continuous flow analysis. Vulnerable to moisture in sample.

TABLE A-3—TITRIMETERS*

*Titration implies the measurement of concentration of an unknown material by virtue of its quantitative reversible chemical reaction with a chemical reagent of known concentration; and, the use of a suitable primary element to detect chemical *equivalence* of the reaction. Titrimetric methods are based on a volume-concentration relationship and resolve into methods of metering *volume* of reagent and process liquor. Instruments serve the purpose of detecting end-point equivalence.

Type	*Measured Effect*	*Application*	*Range*	*Accuracy*	*Remarks*
Potentiometric	Potential difference between suitable indicator electrode & standard reference electrode.	Measurement of total *molecular* concentration of electrolytes.	Low concentration range below 10%.	Under favorable conditions well under 0.5%. Poor potential "breaks" may reduce accuracies to 1%-5% of theoretical.	Applicable to continuous process control. See Fig. 2. Useful in measurement of total acidity. Restricted primarily to aqueous solutions.
Conductimetric	A-c. resistance at 60 or 1000 cps. of test solution.	Ditto above and also mixed solutes of differing ionization constants, i.e., weak acids in presence of strong acids. See Fig. 3.	Dependent on characteristics of material measured. Used in high or low concentration ranges.	0.1% to 5% (or more) of theoretical depending on specific application.	Sometimes applicable when solution potentials are too weak to be resolved potentiometrically.
Photometric	Difference of rate change of color of internal indicators at equivalence. See Fig. 4.	Total molecular concentration or saponification numbers of colored resins, etc.	Generally, medial concentration range.	0.1% to 5% of theoretical.	Applicable when equivalence potential of electrometric method is slow in reaching equilibrium. Can be used on dark-colored solutions with appropriate light filters.
Amperometric	Diffusion current at polarized electrode.	Total molecular concentration of dilute solutions.	Low concentration range, best below 1.0% concentration.	0.1% to 0.5% of theoretical.	Applicable to lower concentrations than potentiometric types, and often the presence of foreign electrolytes do not interfere as in conductimetric methods.
Q-Metric	Effective "Q" of an electronic circuit oscillating at 1 megacycle and containing the test solution impedance as a circuit parameter.	Ditto conductimetric titrimeters.	Ditto conductimetric titrimeters.	Ditto conductimetric titrimeters.	Principal advantage over conductimetric titrimeters; electrodes do not contact solution and require no surface preparation.
Miscellaneous	Important titrimeters of recent development and future promise are (A) Thermometric and (B) Radiometric. (See Langer, U. S. patent 2,367,949). They measure respectively heats of reaction and radioactivity loss.				

SPECIFIC VERSUS NON-SPECIFIC ANALYSIS INSTRUMENTS

Very few analysis instruments are *specific* for a given substance and respond only to that substance irrespective of the presence of other matter. However, from a user's standpoint it is an ideal concept that *all* analysis instruments should be specific for a given molecule and analyze, quantatively, the molecular concentration without interferences from foreign molecules. This ideal rarely occurs. It is not possible in most cases to "expose" any of the common plant-type instruments to an unknown solution and obtain a measure of concentration "X" without knowledge of the history and

TABLE A-4—INDIVIDUAL TYPES OF CLASS "A" INSTRUMENTS

Instrument Methods	*Measured Effect*	*Application*	*Range*	*Accuracy*	*Remarks*
Controlled potential electrolysis	Electroplating current at controlled cathode potentials.	Analysis of metals in mineral ores, particularly rare earths & heavy "atomic" metals, & Cu, Ag, Au, etc.	Trace quantities or 100% assay analysis.	Very high with ions having widely separated decomposition potentials. Lower accuracy with closely related decomposition potentials.	Batch laboratory method. Differing decomposition potentials of metal ions provide means of fractional separation and analysis. Electrolysis potential must be controlled.
Chromatography	Relative rates of migration of solvent & solute in an adsorptive phase.	Separation & resolution of complex constituents in solution.	Micro analysis of trace quantities or low concentration range.	5% to 10% of theoretical.	Laboratory procedure. Adsorptive phase may be column of silica gel, celite, etc. or strips of filter paper.
Combustion processes	Electrical resistance (temperature) of hot wire which sustains combustion of test gas & reagent fuel. Or thermal conductivity before and after combustion.	Oxygen gas analysis or combustibles gas analysis.	0-5%; 0-25% . . . 0-30% . . .	0.25% of range. 5% of theoretical.	Industrial instruments for continuous flow measurement & control.
Polarized electrolysis cells	Electrolysis current of cell wherein cathode is depolarized by test gas diffusing through porous walls.	Oxygen analysis	0-½% O_2 0-25% O_2	Low range, 0.01% of theoretical. High range, 0.25% of theoretical.	Continuous analysis instrument. Limited to gases free of Cl_2, SO_2 & similar depolarizers.
Scrubbing & extraction	Thermal conductivity of gas scrubbed from solution by suitable reagent scrubbing gas.	Disolved oxygen & dissolved hydrogen in boiler feed water.	0-0.2; 0-0.5 & 0-1.0 ppm. O_2: 0-20 parts per billion H_2.	5% theoretical O_2 5% theoretical H_2	Continuous stream analysis. Industrial type.
Adsorption fractionation	Closely boiling hydrocarbon fractions are separated in a fractioning column containing activated carbon. Highest boiling constituent is adsorbed lowermost in column & lowest boiling constituent uppermost. A movable heater drives the adsorbed fractions out of the column into a volume metering device & thermal conductivity analysis cell which identifies each constituent.				

general composition of the solution. Some instruments of a research nature, to be described in Chapter XIV, are applicable in a limited way to the analysis of the composition and concentration of constituents specifically of an unknown sample. For example, the arc spectograph is widely used in metallurgical analysis to identify all constituent metals of a given sample. Although best adapted to trace analysis and the low-concentration ranges, it produces spectra which, with the aid of a densitometer, catalogs quantitatively, all constituents of the sample.

Instruments described in the following sections are non-specific. They are of the general type used in industrial practice and for the most part, require prior calibration or appraisal for a specific application. The listing does not comprise all individual instruments of a given class. Representative types are described and the listing will be amended as new types become available.

II. CLASS "A" INSTRUMENTS-CHEMICAL PROPERTIES TYPES

Chemical properties connote a measurable quantity resulting from chemical reaction of the test material and a standardized reagent, direct or indirect: chemical absorption, electrolysis, photolysis, heats of reaction, chromatography, adsorption or other *chemical* properties which distinguish a given material and serve to identify it. Chemical reagents or secondary supporting agents are usually required and the characterizing measurement of concentration is related directly to concentration of the reagent or indirectly to the supporting agent. Tables A-1 to A-4 cover a partial listing of some of the common non-research type industrial instruments.

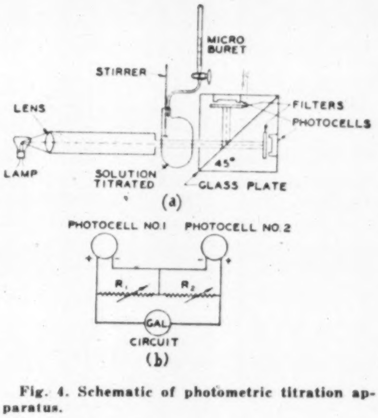

Fig. 4. Schematic of photometric titration apparatus.

III. CLASS "B" INSTRUMENTS-PHYSICAL PROPERTIES TYPES

The foregoing Class "A" instruments are characterized only by their use of *chemical reagents* to effect a measurable quantity which expresses chemical concentration. The measurable quantity is the result of a chemical reaction and

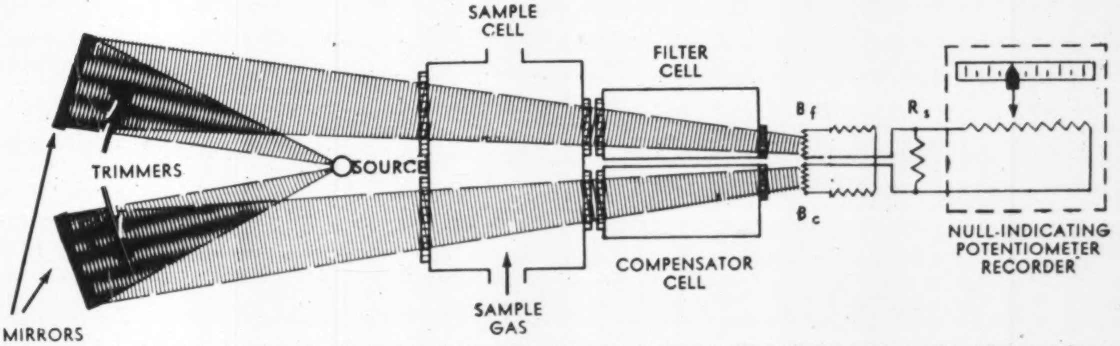

Fig. 5. Negative filter-type infrared filter photometer. Analyzed constituent gas is placed in filter cell. Bolometer signal is difference before and after absorption in filter cell.

Table B-1—PHOTOMETERS

In its original sense, photometry was designated as that phase of radiometry which dealt with the measurement of visual light. Its connotation in analysis instrumentation has been extended to embrace all types of instruments which measure absorption of energy at a specified wavelength throughout the electromagnetic spectrum. The magnitude of absorption (of monochromatic radiation) is a function of concentration in accordance with Beer's law. Only the non-dispersing instruments are treated in this chapter.

Instrument Type	*Measured Effect*	*Application*	*Range*	*Accuracy*	*Remarks*
Colorimeters	Depth or hue of color of light transmitted by sample compared to standard.	Laboratory routine analysis of solutions amenable to color measurements with or without internal indicators.	Generally low concentration range, but dependent on color depth.	May be low, 15%-30% of theoretical dependent upon analyst's vision. Best accuracy is 1%-10%.	Widely used laboratory instrument but limited by analyst's color vision.
Nephelometers	Intensity of monochromatic light scattered at right angles to axis of incident light beam.	Measurement of concentration of disperse colloids or suspended particles in solution; turbidity, etc.	Dependent inversely on particle diam. & 4th power of light wavelength. Generally low concentration range.	Kober type visual instrument or photoelectric type 1% of theoretical.	Method is capable of extreme sensitivity, i.e., 1 part in 300 million.
Fluorophotometers	Relative intensity of fluorescence of sample compared to a standard excited with ultra-violet light.	Analysis of rare earths in microquantities. Oxygen in range $1x10^{-11}$ mol.	Quantitative in microrange. Qualitative in higher concentrations.	1%-5% of theoretical in trace analysis.	Capable of extreme sensitivity. More accurate than Nephelometery because of absence of diffuse reflections.
FILTER PHOTOMETERS					
(a) Visible light	Per cent transmission of monochromatic light in the visible range compared to standard.	Ditto colorimeters.	Ditto colorimeters.	Use of photocells to replace human eye increases accuracy ten-fold over colorimeters.	Probably most widely used of all laboratory instruments. Double beam instruments are used in continuous flow analysis & control.
(b) Ultraviolet	Per cent transmission of monochromatic energy in the range 2500A°-3650A°. Usually compared to reference standard.	Absorption of UV energy by conjugate double bonds, ring-structured molecules & some inorganic molecules gives measure of concentration.	Best for trace quantities & concentrations below 10%.	0.1%-5% of theoretical.	Suitable for analyzing low concentrations H_2S, Cl_2, $C_6H_6Cl_3$, xylene, acetone, C_2Cl_2, O_3, aniline CS_2, Applicable to continuous process control.
(c) Infrared	Per cent transmission of monochromatic energy in the range 2.5 to 25 microns, compared to standard. See Fig. 5.	Usually analysis of gases which absorb IR energy. Has also been applied to liquid in liquid analysis.	Low concentration range. Usually below 20%.	0.1%-10% of theoretical dependent on specific conditions. Sensitivity can be increased by "pressure broadening." High conc. analysis limited by sensitivity saturation. See Fig. 7.	Instruments best adapted to gas analysis because the condition of one constituent showing strong absorption in a weak field from interferences is favored more by gases than liquids.
(d) X-ray	X-rays have a wavelength of approximately 1A° and have high intrinsic energy. They affect only the electrons of the atomic nucleus. They do not respond to electronic orbit arrangements which determine chemical properties as do infrared or ultraviolet and, therefore, the absorption pattern for a given element is independent of its state of aggregation. The pattern remains unchanged whether the element is free or combined. The method is best adapted to analysis of high atomic weight elements.				
(e) Flame Photometers	Intensity of characteristic color imparted to neutral blue flame. Photocell detection.	Anlysis of alkaline earth metals, viz. Na, K, Sr, Ca etc.	100 ppm. or below. Or 4000 ppm. & below.	± 1.25% to ±3.0% of theoretical.	Laboratory Instruments.

Table B-2—REFRACTOMETERS

Refractive index is an additive function which constitutes a measurement of concentration of liquid mixtures when the total volume of solution is equal to the sum of the volumes of its constituents. Or specific refraction of molecular refraction is characteristic of chemical compounds. Specific dispersion constitutes a measurement of refractive index at two different wavelengths of light and expresses a characteristic function of liquid composition. Transparent or opaque solids may be measured but, for the most part, industrial measurement of refractive index are confined to liquid measurements.

Type	*Description*	*Application*	*Range*	*Accuracy*	*Remarks*
Minimum deviation method.	A prism is made of the material whose refractive index is to be determined. The angle of light deviation is related to its refractive index.	Measurement of transparent solids or liquids. A hollow glass prism through which a liquid is circulated has been applied to continuous process control. See Fig. 6.	Unlimited. This is the classical method for fundamental determinations. Industrial fluid instrument range 1.1500 to 1.4700.	Very high. See L. W. Tilton, *U. S. Bureau Stds., J. Res.*, Vol. 14 P. 393 (1935) for discussion of factors affecting accuracy.	Widest range of common industrial refractometer methods. See U.S. patent 2,413,208. Industrial type instruments restricted to low pressure transparent fluids.
Total Reflection method	A transparent cylindrical or trapezoidal prism is surrounded by or contacts the solution to be measured. Ratio of scattered to transmitted light is related to difference of indices of prism & solution.	Measurement of opaque or transparent fluids at atmospheric or elevated pressures. See Fig. 8.	Limited. Dependent on relative index of prism & fluid measured. Pressure range 0-150 psig.	±0.00004 to ±0.00005	Limited rangeability. Principle well adapted to industrial instrumentation.
Critical angle dipping type	A prism dipped into or submerged in the fluid measured refracts light & produces a light & dark field divided by a "critical index ray." See Fig. 9.	Measurement of transparent fluids.	Usually narrow rangeability, i.e., .04 (1.32-1.36).	Usually ±0.00003 to ±0.00004.	Only known commercial recording refractometer.

TABLE B-2—REFRACTOMETERS (*Continued*)

Type	*Description*	*Application*	*Range*	*Accuracy*	*Remarks*
Differential Refractometer	A beam of light passing through two divided liquids is refracted as a function of the difference in indices of the two fluids.	Difference concentration of two fluids. Or percentage composition of test fluid compared to pure constituent.	Range of coverage usually narrow but sensitivity is high. Pressure range low.	Full scale range 0.0002; sensitivity 0.000002 at 1% accuracy. Full scale at minimum sensitivity 0.01 to 1% accuracy.	Suitable for continuous stream analysis.

Refractometers require pure monochromatic light, usually the sodium "D" line or mercury green line. They are critically affected by temperature and require temperature regulation. Condensation fogging of prism surfaces has been a source of trouble in minimum deviation type continuous stream controllers operating at below ambient temperatures. All continuous flow refractometers have this limitation. Refractive index 1.9 is usual top limit of industrial refractometers.

TABLE B-3 INDIVIDUAL TYPES OF CLASS "B" INSTRUMENTS

Instrument Type	*Measured Effect*	*Application*	*Range*	*Accuracy*	*Remarks*
Thermal Conductivity	Electrical resistance (nominal 5 to 20 ohms) of a heated wire (2 mil) at constant current or potential in contact with analysis gas.	Analysis of gases having amenable thermal conductivities, viz. H_2, Cl_2, CO_2, SO_2, etc.	0-10%; 30% or 100% dependent on gas composition.	Usual 1%-15% of theoretical. Error can be 100% or more if instrument not properly applied.	One of the most practical instruments for industrial gas analysis within its limitations.
Electrical Conductance	A-c. electric resistance of solution contained between appropriate electrodes.	Solution analysis, viz. H_2SO_4 strength, water purity, condenser leakage, salt concentration, etc.	May be limited or 100% coverage depending on solution characteristics. Applicable to dilute solution analysis.	0.1% to 10% of theoretical dependent on application.	Electrode maintenance limiting factor. D.c. can be used above 1 megohm measured resistance at low concentrations.
pH	D-c. potential difference between indicator electrode (usually glass) and fixed reference electrode. (Approx. 60 mv per pH change).	Measurement of active acidity in solution, principally aqueous.	0-14 pH	Usually 0.1 pH for industrial instruments.	Available as continuous process controllers.
Dielectric Constant or Dielectric Loss	Effective capacity at 1 to 3 megacycles of test fluid contained between fixed electrodes. Or current phase angle caused by current losses in dielectric.	Fluid analysis, usually at frequencies above dispersion range. Viz., H_2O .... D=80 CH_3OH .... 31.2 C_2H_5OH .... 25.8 C_6H_6 .... 2.29	D=1 to 6 insulating dielectrics; 6 to 30 semiconducting dielectrics; 30 to 100 conducting dielectrics.	Varies with constituents of fluids measured. 10 ppm. or above.	Dielectric loss measurements at usual accuracy of 5%-10% theoretical are most amenable to industrial instrumentation.
Fractional Distillation	Precise regulation of distillation parameters effects close separation of boiling constituents. Top temperature identifies constituent.	Separation & identification of hydrocarbon mixtures.	Liquids having boiling points -160 C. to 350 C.	Resolution of boiling temperatures 0.05 to 0.10 C.	Widely used for laboratory separation & identification of hydrocarbon mixtures.
Calorimetry	Temperature difference between "freezing" solid & inert standard contained in Calorimeter.	Measurement of melting point or freezing point identifies purity of solid compound.	Usual range used 100-1500 F.	Low temperature range, resolution 0.50. High temperature range 3 F.	Laboratory type instruments. Automatically regulates rate of temperature change in calorimeter & plots freezing curves.
Acoustic Gas Analysis	(a) *Frequency Shift* Change in frequency of a signal passed through test gas.	Measurement of gases having high molecular weight. Frequency shift is function of molecular weight.	Generally determined by differences in molecular weights of gases in mixtures to be resolved.		See U. S. patent 2,283,750 applicable to continuous stream analysis.
	(b) *Sound Velocity* Length of nodal points or velocity of constant frequency signal passed through test gas.	Measurement is a function of gas density.	Accuracy & range is contingent upon mixture of gases measured. H_2 in air, O—100% in 6% spans: CO_2, O—33% in 16% spans: CH_4, O—40% in 20% spans.		Laboratory measurements.

is directly related to concentration of the desired constituent.

Class "B" instruments do not use chemical reagents. They measure concentration by direct measurement of one or more *physical properties* of the material sought. There is no distinction in terms of primary elements. Both classes use the same detectors.

Tables B-1 to B-5 give a partial listing of some of the more common nonresearch type Class "B" instruments generally used in the laboratory and/or applied to continuous process control.

IV. PURIFICATION TRAINS

Almost all analysis instruments require the use of purification trains to

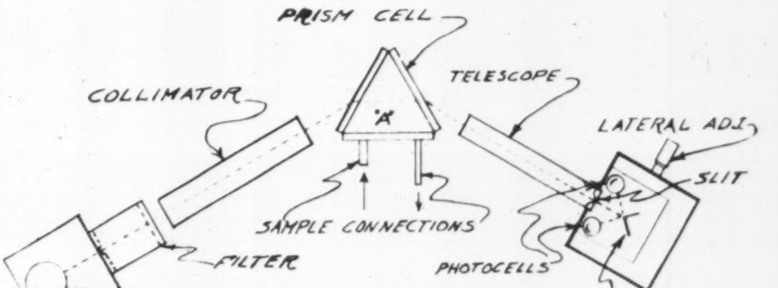

Fig. 6. Minimum deviation-type refractometer for continuous recording and control.

TABLE B-4—MAGNETIC PROPERTIES

Instrument Type	*Measured Effect*	*Application*	*Range*	*Accuracy*	*Remarks*
Magnetic-Optical Rotation	**Optical rotation of polarized monochromatic light beam passing through test specimen contained in magnetic field.**	Identification of **Tautomerism in aromatic ring structures** viz. benzenoid & napthenic hydrocarbons. Mixtures of benzene & cyclohexane & hexane, etc.	Low concentration ranges.	To 0.5% theoretical depending on liquid **mixtures**	**Laboratory apparatus primarily adapted to hydracarbon analysis.**
Ferro-magnetism	Impedance of test coil at two different frequencies (250 & 500 cps) containing test specimen **as** core.	Metals comparator. Carbon in steel or similarity of test specimen & standard.	Useful in sorting & classifying metal stocks or some non-magnetic materials. Iron content 0.006% to 0.021% in copper resolved.		Instrument standardized on standard sample to which **test specimen is** compared.
	MAGNETIC SUSCEPTIBILITY A substance placed in a magnetic field is said to be *diamagnetic* if it is less permeable than a vacuum, or *paramagnetic* if it is more permeable. The paramagnetism of certain gases, particularly oxygen, renders the method particularly outstanding for instrument analysis. See P. W. Selwood, "Magnetochemistry," Interscience Publishers, New York, N. Y. Fig. 10 expresses relative paramagnetism of common gases with oxygen taken as 100%.				
Faraday Non-Uniform Field Method*	Electrostatic force necessary to restore a torsion indicator to null balance in a non-uniform paramagnetic field.	Oxygen Gas analysis. See L. J. Pauling U. S. Patent 2,416,344.	Min. Std. range is 0-1% with sensitivity of 200ppm & accuracy of 0.02% of theoretical. Max. range 0-100% with accuracy of ±1.0% of range.		The NULL balance measuring principle of this instrument **adapts it to wide range measurements with high accuracy.**
Thermal Agitation Method**	Difference in resistance of two hot wires in test gas. Magnetic field effects thermal agitation in one leg.	Oxygen gas analysis.	Min. Std. range 0-2% with an accuracy of ±0.1%. Maximum range, 0-100%, accuracy ±2%.		Rugged construction for continuous industrial flow measurement & control.

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*So classified by the writer because Michael Faraday first observed that a body placed within a non-uniform magnetic field is attracted to the denser field with a force proportional to its paramagnetism.

**Early workers in the field of Magnetochemistry observed that gas molecules in a uniform magnetic field enter into thermal agitation proportional to their paramagnetic properties.

TABLE B-5—DENSITY & SPECIFIC GRAVITY

Instrument Type	*Measured Effect*	*Application*	*Range*	*Accuracy*	*Remarks*
Tuning fork method	Resonant frequency of vibration of a tuning fork or resonant cavity through which the test fluid flows.	Measurement & control of fluid density at low or high pressures.	Range & accuracy is dependent on relative density of tuning fork & test fluid. Industrial fluids sp. gr. 1.0-1.89, accuracy 100 ppm.		Applicable to continuous process flow measurement & control. Not flow critical.
Hydrometer Partially or Totally submerged	Magnetic coupling in transformer bridge surrounding hydrometer or intensity of light beam intercepted by hydrometer head.	Liquid specific gravity measurements at atmospheric pressure.	Full range sp. gr. measurements with scale spans 0.005 to .05.	0.0002 or 3% of range whichever is greater.	**Satisfactory for continuous flow measurements but flow critical outside narrow limits.**
Totally submerged float	Aid pressure from pneumatic pilot resulting from bouyant force on totally submerged float.	Liquid sp. gr. or density measurements at atmospheric or very high pressures or vacuum.	Usual range of coverage 1.0-2.9 sp. gr. depending on float dimensions.	Approx. 0.01 to 0.005 sp. gr.	Rugged industrial instruments. Flow critical outside narrow limits.
Recording Pycnometer	Air pressure which **counteracts** weight of fixed volume sphere through which test solution flows continuously.	Liquid density or sp. gr. measurements at normal or high pressures.	Full range coverage in scale spans of 0.05 or 0.1 sp. gr.	0.0005 to 0.001 sp. gr.	Instrument **is flow** insensitive over wide range.
Pneumatic bubble tube or submerged air reaction diaphragms	**Difference** in back pressure between two air bubble tubes submerged at different elevations.	Measure liquid density or sp. gr. in processing vessel or continuous flow chamber.	Usual range of application 0.8-2.0 sp. gr.	0.1 to 1 in. W. C. pressure corresponding.	Air must **be bubbled at constant rate. Applicable** to suspensions & measurements under pressure within limits.
Cartesian diver	Air pressure above liquid necessary to establish equilibrium balance of a submerged glass baloon in test liquid.	Liquid density measurements at atmospheric pressures.	Range very narrow. Dependent on relative densities of baloon & test liquid.	Dilute solutions in order of 0.1% with accuracy of 0.03% of theoretical.	Laboratory instrument. Non-flow type.
Drap cup density balance	Difference in drag torque of two floating vane wheels coupled to driven wheels through gas to be measured.	Usually applied to boiler CO_2 analysis. Compares drag of test gas to drag of standard air.	Usual range coverage 1.0-1.3 sp. gr.	Approx. 0.01 sp. gr. with viscosity compensation.	Instrument must be standardized at known viscosity. Continuous flow analysis at atmospheric or elevated pressures.
Edwards gas density balance	Pressure difference necessary to balance a bouyant float at neutral in a medium of air & test gas.	Compare densities of two gases or of test gas & standard air at fixed temperature.	Applied range, 0.6100 to 2.0500.	Approx. 0.0005.	Laboratory non-continuous instrument.

Space limits description of all available instruments. The reader is referred to U. S. Dept. of Commerce Misc. Publication M177, "Tests of Instruments for the Determination, Indication or Recording of the Specific Gravities of Gases." This book presents an exhaustive comparative analysis of various instrumental methods.

remove impurities and "gunk" or to pretreat the sample prior to measurement. These trains are usually assembled from standard laboratory glassware. Various chemicals such as concentrated sulphuric acid, phosphorous pentoxide, volatile organic solvents etc., are used to pretreat the sample prior to analysis.

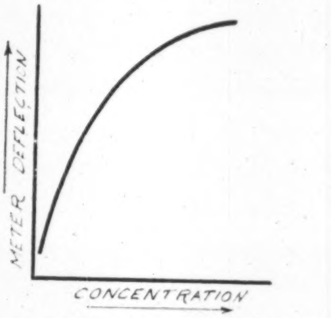


Fig. 7. Typical saturation characteristic of many Class B analysis instruments.

Pretreatment is quite necessary and scrubbing trains are satisfactory in laboratory usage, but efforts to adapt them to plant instrumentation have not been successful. In their present stage of design, they are the major source of complaint which plant people have against analysis instruments.

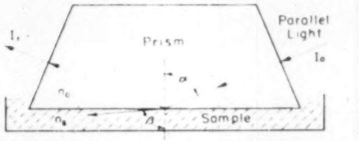
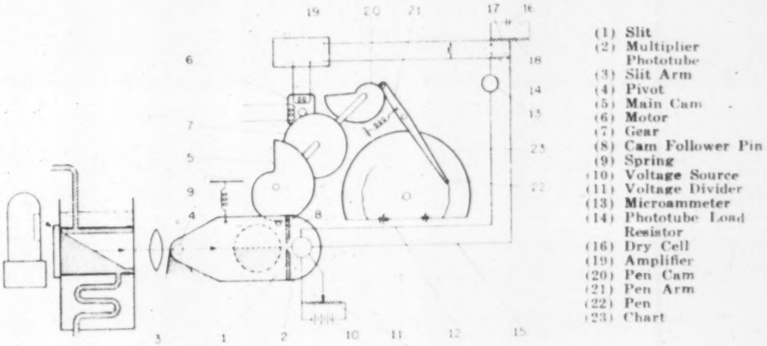

Parallel Light
Prism
I₁
I₀
n₀
nₛ
α
Sample

Fig. 8. Trapezoidal prism for single-reflection refractometer.

V. ANALYSIS INSTRUMENTS AS CONTROLLERS

The concept of applying analysis instruments to measure concentration of process constituents suggests their use to measure *end product* and regulate all variables to obtain maximum yield. Unfortunately, this cannot be done and analysis instruments are limited in their mode of application as process controllers. They have been successfully applied to perform two control functions.

A. *Physical Separations*:—Mixtures which are separated in the absence of a chemical reaction such as distillation, extraction, absorption, etc., have no anomalous characteristics and are amenable to automatic regulation with analysis instruments. Reflux control on distillation columns has been a successful application replacing less sensitive temperature methods of separation.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(1) Slit
(2) Multiplier Phototube
(3) Slit Arm
(4) Pivot
(5) Main Cam
(6) Motor
(7) Gear
(8) Cam Follower Pin
(9) Spring
(10) Voltage Source
(11) Voltage Divider
(13) Microammeter
(14) Phototube Load Resistor
(16) Dry Cell
(19) Amplifier
(20) Pen Cam
(21) Pen Arm
(22) Pen
(23) Chart

Fig. 9. Principle of recording immersion refractometer.

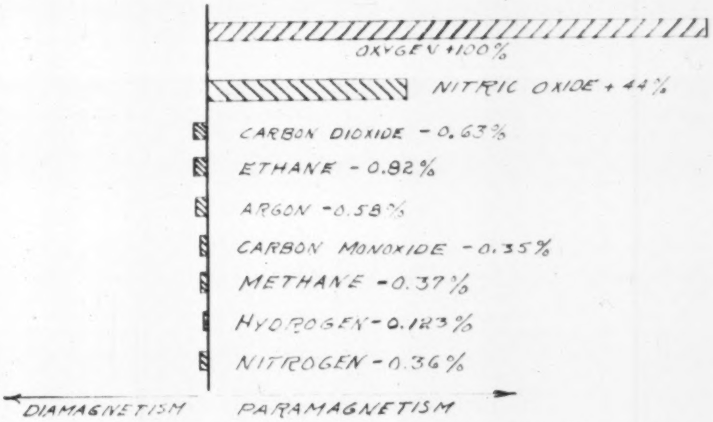

Fig. 10. Relative paramagnetism of some common industrial gases.

B. *Reaction Arrestors*:—In certain processes it is desirable to add *reactants* to a batch operation until a reactant or a catalyst appears in excess. At this point some regulatory steps must be taken. Or, in continuous processing it is sometimes desirable to maintain a definitely known excess of *reactant* or catalyst or it may be necessary to maintain concentration *environment* of a reaction at specified value. Analysis instruments have successfully and profitably served in this capacity.

As a general rule, these instruments cannot be applied directly, or indirectly as reset devices to measure concentration of end product and regulate feed of reactant to obtain stoichiometric yields.

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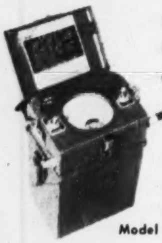

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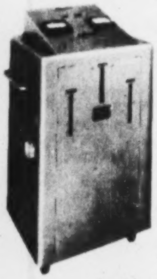

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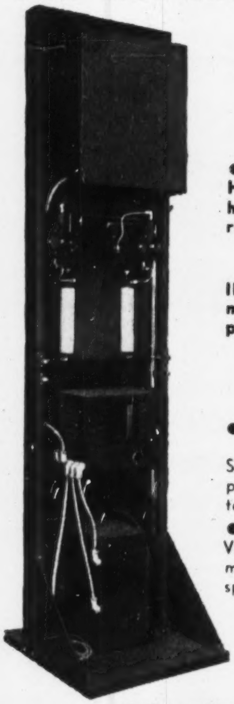

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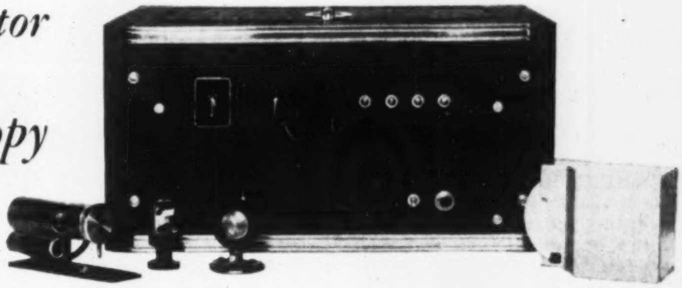

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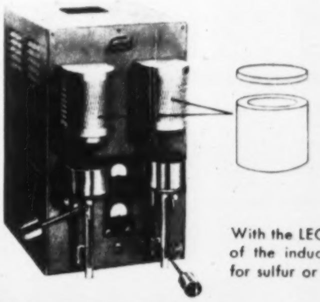

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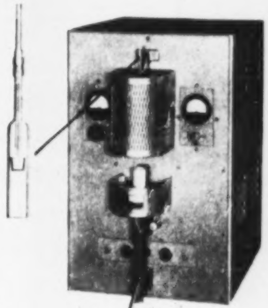

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CHAPTER VII

DETERMINING PHYSICAL PROPERTIES AND TESTING FINISHED PRODUCTS

By HOWARD C. ROBERTS

SIGNIFICANCE OF THE TERM "PHYSICAL PROPERTY"

MOST of the measurements made in the plant or laboratory are of discrete values—measurements of quantity, of rate, of time, and the like. There are many specific instruments for such measurements. The determination of physical properties, however, usually cannot be accomplished so easily, nor so directly, as measurements of magnitude.

The word "property" is defined by the dictionary as "whatever belongs or pertains to any object"; and properties are usually classified as those of quality or action (intrinsic and essential), and those of relation or of condition (extrinsic and non-essential). The physical properties pertaining to materials are those of quality and of condition; they are most often those characteristics which serve to identify a material, to indicate its purity or strength, or to evaluate its behavior under some set of conditions.

It is obvious that a measurement of dimension cannot describe a property; neither the volume nor the mass of a solid, for example, can possibly serve to identify the material of which it is composed. The quotient of these two, however, is the density of the material, and density is a property—a characteristic of the material. Since two magnitudes are involved, the term "determination" is more suitable than "measurement." A single measurement of dimension may, under certain circumstances, be used as a criterion of acceptance of a finished product.

Most of the physical properties with which the user of this Handbook is concerned must be determined by measuring more than one magnitude and performing a computation, as in the determination of density. For convenience, the apparatus is often so made that it automatically performs the computation; thus, the specific gravity of a liquid may be determined by means of a hydrometer or a pycnometer—instruments which, in a single operation, take into account both the mass and the volume of the liquid sample.

The essential factor in the determination is not the particular instrument employed, but the METHOD. Economic considerations have impelled designers to produce specialized instruments for easy determination of the more useful physical properties; such instruments are practical and economical. Actually, the work which can be done so easily with their help could also be done by

GROUP 1: IDENTIFICATION OR ACCEPTANCE TESTS

TABLE 1:1. PHYSICAL PROPERTIES: LABORATORY

Name of Property	*Method or Instrument Name*	*Materials*	*Principle or Phenomenon*	*Accuracy; other notes*
Linear expansion	Dilatometer	Any solid	Measurement of elongation with increase in temperature	High, depending upon techniques Apparatus available for many kinds and sizes of specimens
Density or specific gravity	Pycnometer; liquid-displacement method	Any solid	Volume determined by liquid displacement, weight by scale	High, depending upon technique
Density or specific gravity	Hydrometer, pycnometer, Westphal balance, etc.	Any liquid	Directly-graduated devices; pycnometer requires weighing	High
Porosity	Water-absorption method; balances	Any solid not soluble in water	Increase in weight due to absorption of liquid	Moderately high, 1 percent possible
Fluid permeability	Fluid permeameter	Any solid	Volume of fluid permitted to pass per unit time at known pressure	Moderately high, 2 percent possible
STRENGTH OF MATERIALS:				
Modulus of elasticity	Testing machine, strain gage	Any solid which can be formed into a specimen	Quotient of unit stress and unit strain	High; depending upon technique
Yield strength	Testing machine, strain gage	Any solid which can be formed	Load at which strain increases non-linearly	Moderately high, 2 percent usual
Tensile or compressive strength	Testing machine, strain gage	Any solid which can be formed	Maximum stress before failure	Moderate, 2 to 5 percent
Elongation before failure	Testing machine, strain gage	Any solid which can be formed	Permanent elongation of 2-inch length of specimen	Moderate, 2 to 5 percent
IMPACT RESISTANCE:				
Tensile impact	Modified pendulum machine	Any metal	Pendulum impact on notched tension specimens	Moderate, 2 to 5 percent
Simple-beam impact	Pendulum machine, Charpy	Any metal	Pendulum impact on notched simple-beam specimens	Moderate, 2 to 5 percent
Cantilever-beam impact	Pendulum machine, Izod	Any metal	Pendulum impact on notched cantilever-beam specimens	Moderate, 2 to 5 percent

TABLE 1:2. ELECTRICAL AND MAGNETIC CHARACTERISTICS

Name of Property	*Method or Instrument Name*	*Materials*	*Principle or Phenomenon*	*Accuracy; other notes*
Specific resistivity	Resistance bridge, usually Wheatstone or Kelvin	Any conducting material	Electrical resistance versus dimensions	0.01 percent in laboratory conditions. Dimensional measurement required.
Dielectric strength	High-voltage source	Any insulating material	Voltage breakdown	......Voltage at breakdown usually observed; noted as within tolerance
Specific inductive capacity	Capacity bridge	Any insulating material	Ratio of capacitance of test cell with air dielectric to capacitance with unknown	0.05 percent. Frequency may affect values; resistance must be considered
Thermoelectric power	Potentiometer, constant-temperature chambers	Any metals	Production of potential at junctions of dissimilar metals	0.03 percent; higher under precision conditions
Magnetic properties[*] of ferrous materials:				
Magnetic force Normal induction Normal permeability Residual induction Coercive force	Rowland-ring method Burroughs double yoke Fahy permeameter High-H permeameter Saturation permeameter	Any soft steels Any magnetic material Any magnetic material Any magnetic material Any magnetic material	This entire group of properties is determined with apparatus which makes possible measurement of the magnetic field produced by known currents through standard coils; details may be found in ASTM Spec. A-34	Normal induction, 1 percent Residual induction, 2 percent Coercive force, 5 percent
Core loss	Epstein apparatus	Any core materials	Measurements of watts absorbed in core of a transformer containing test material as core.	2 percent
Interlamination resistance	Resistance bridge	Any lamination materials	Measurement of ohmic resistance through stack of laminations	Normally not high, about 1 percent. Used only as criterion of quality of stacking.

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[*] American Society of Testing Materials designations.

TABLE 1:3. RHEOLOGICAL PROPERTIES, HARDNESS, ETC.

Name of Property	*Method or Instrument Name*	*Materials*	*Principle or Phenomenon*	*Accuracy; other notes*
DUCTILITY:				
Elongation of metals	Tension testing machine, extensometer	Any metal	Measurement of permanent elongation at failure	1 to 3 percent
Deep-drawing properties	Compression test in die	Any sheet metal	Die-drawing of cup: visual	...Inspect visually for rupture
Bendability	Bend-test machine	Any metal	Bend-test in die; visual	...Inspect visually for cracking
CONSISTENCY:				
Slump of wet mixture	Slump test	Concrete, mortar mix	Slump of mix under its own weight	...Measure to 2 to 5 percent
Flow under vibration	Flow test	Concrete mix	Flow of mix when shaken vertically	...Measure to 2 to 10 percent
Sticky point	"Sticky-point apparatus"	Soils	"Stickiness" to surface	U.S.D.A. Bulletin No. 562
Softening under heat	Ball and ring test	Asphalts, tars, etc.	Flow as heated	5 to 15 percent
Plasticity*	Viscometer	Any soft material	Rate of flow versus force	1 to 5 percent
Viscosity*	Viscometer	Any fluid material	Rate of flow versus force	1 to 5 percent
HARDNESS:				
Brinell	Brinell hardness tester	Any solid except thin sheet	Indentation by sphere	1 to 2 percent. Best for large pieces.
Rockwell	Rockwell tester	Any solid	Indentation by cone	1 to 2 percent. Best for thin sheets.
Diamond pyramid	Diamond pyramid tester	Any solid	Indentation by pyramid	1 to 4 percent. Best for close spacing.
Scleroscope	Scleroscope	Any metal	Rebound of falling weight	2 to 5 percent

*It is most convenient to distinguish between viscosity and plasticity by noting that when the rate of flow is plotted against the applied force the curve passes through the origin when the material is viscous, but that it intersects the force axis at some point above zero when the material is plastic. The same instrument may be used for both tests.

TABLE 1:4. THERMAL PROPERTIES

Name of Property	*Method or Instrument Name*	*Materials*	*Principle or Phenomenon*	*Accuracy; other notes*
Melting point	Refrigerator; thermocouple	Low melting-point materials, —300 to 50 F.	Visual observation; critical points in cooling curve	1 to 2 percent; over certain ranges, 0.1 percent
Melting point	Hot-plate; thermometer	Moderate melting-point materials, 100 to 500 F.	Visual observation; critical points in cooling curve	1 to 2 percent; over some ranges, 0.1 percent
Melting point	Furnace, thermocouple, or optical pyrometer	High melting-point materials, 300 to 3000 F.	Observation of melting point	1 to 5 percent
Boiling point	Refrigerator; thermocouple	Low boiling point materials, —300 to 50 F.	Critical points in cooling curve	1 to 2 percent
Boiling point	Hot-plate; thermometer	Moderate melting-point materials, 100 to 500 F.	Critical points in cooling curve	1 percent
Boiling point	Furnace; thermocouple or optical pyrometer	High boiling point materials, 300 to 4000 F.	Critical points in cooling curve	1 to 5 percent
Specific heat	Calorimeter	Any material	Change in temperature of known substances	0.1 to 1.0 percent. Technique is somewhat difficult, important
Thermal conductivity	Thermal conductivity apparatus	Any; apparatus and specimen to suit	Rate of flow of heat along or through specimen	1.0 percent. See ASTM Spec. C-177 and D-325

TABLE 1:5. MECHANICAL PROPERTIES (OTHER THAN STRENGTH)

Name of Property	*Method or Instrument Name*	*Materials*	*Principle or Phenomenon*	*Accuracy; other notes*
Hardenability	End-quench or Jominy Test	Steels	End-quench with water jet; hardness by Rockwell test	Qualitative. See ASTM Spec. A-255
Machineability	Herbert method	Any machineable metal	Measurement of force on lathe tool; hardening and smoothness of the turned surface	Qualitative, depending upon technique

TABLE 1:6. SPECIFIC IDENTIFICATION METHODS

Name of Property	*Method or Instrument Name*	*Materials*	*Principle or Phenomenon*	*Accuracy; other notes*
X-Ray diffraction	Hull-Hanawalt method	Any crystalline material	X-Ray diffraction pattern	Qualitative
Spectrographic	Spectroscope, Spectrometer	Any material	Radiation, absorption, or resonance spectra	Qualitative; some use in quantitative analysis.

GROUP 2: PROPERTIES OF REFINED PRODUCTS, BUILDING MATERIALS, ETC.

TABLE 2:1. STRUCTURAL SOUNDNESS OF MATERIALS

Name of Property	*Method or Instrument Name*	*Materials*	*Principle or Phenomenon Involved*	*Resolving Power; other notes*
Inclusion content of metals	Magnetic particle method	Principally ferrous metals	Aggregation of magnetic particles about magnetic inhomogeneities	Resolving power depends largely on preparation and techniques; inclusions smaller than 1/64 inch not usually reliably found
Inclusion content of materials	Macroscopic and microscopic examination	All metals, most solids	Prepare surface inspected visually, either with or without etching	Resolving power depends principally on the technique used
Soundness of solids	Radiography	Nearly all solids	X-ray "shadowgraphs"	Usually limited to about 3 percent of thickness
Soundness of solids	Ultrasonic; reflection of sound pulse	Most solids	"Echoes" from discontinuities	High but highly variable; size, shape, and condition of specimen is important
Homogeneity	Magnetic analysis	Principally ferrous* metals	Change in magnetic induction with flaws, voids, or other inhomogeneities	Comparative only. May be given extremely high resolving power, but surface and other irrelevant conditions may make this impractical

*Some extremely ingenious and useful methods have been developed for magnetic inspection of non-magnetic metals, but they have had little use as yet except in a few research laboratories.

ordinary single-purpose laboratory instruments: the balance, the thermometer, scale, etc. The greatest value of the specialized instruments lies in the fact that much time can be saved through their use, and in the greater accuracy that may be expected from semi-skilled personnel if they are provided with such instruments.

"ENGINEERING" *versus* "LABORATORY" PROPERTIES

Excepting in the research laboratory where work on the fundamental properties of matter is in progress, there are in general three reasons for making determinations of the physical properties of materials. They are:

(1) To identify materials or to ascertain if the materials conform to some stated specification;

(2) To estimate how satisfactory will be the material in some projected application; and

(3) To determine the probable performance of the material in extended service.

The first of these might be typified in a standard test on structural steel, or a moisture determination of grain; these tests indicate whether or not the material conforms to an arbitrary acceptance specification. The second might be the inspection of a billet of steel for voids or other non-homogeneities, or a test to determine the bearing strength of a soil before constructing a building upon it. The third is usually some form of service test—a fatigue test of metal, a freezing-and-thawing test of concrete blocks, a color-stability test of textiles, paper, or paint.

These three classes of tests are also distinguished by the fact that the first class is normally performed in the laboratory under some standardized set of conditions, and to relatively high accuracy; the second class may be performed in laboratory, plant, or field, and is usually less accurate quantitatively; the third may or may not be quantitative. (The methods in this third group are, however, continually being made more accurate, quantitatively.)

In the first group, too, appear those tests employed to assess the value of raw materials; in the second, the testing devices for inspection of refined products.

Especially interesting to structural and mechanical engineers and to the manufacturers of a multitude of products, are the elastic constants of mate-

TABLE 2:2. OPTICAL AND VISUAL PROPERTIES; COLOR

Name of Property	*Method or Instrument Used*	*Materials*	*Principle or Criterion Employed*	*Accuracy; other notes*
Reflecting power, diffuse	Reflectometer	Any light colored, smooth	Ratio of amount of light reflected from the unknown from standard surface, measured with integrating sphere	1 to 2 percent
Reflecting power, specular	Glossmeter, or glarimeter	Any having specular reflecting surfaces	Ratio of light reflected specularly from unknown and from standard surfaces, measured directly	1 to 3 percent
Opacity of thin sheets	Reflectometer, photometer	Thin semi-transparent sheet materials	Ration of reflectance of unknown over a standard black backing to that of unknown over a standard white backing	2 to 5 percent. For thick materials, a photometer is used
Haze of transparent materials	Haze-meter, or Priest-Lange reflectometer.	Transparent sheet materials	Proportion of total transmitted light that is scattered from the beam	Haze-meter, 3 to 8 percent. Priest-Lange photometer, about 1 to 3 percent
Tinting or covering power of pigments	Inspection of coated surfaces	Paint pigments, colors	Weight of pigment required per unit area, to cover a standard color, or to duplicate tint	Variable, but not high. 2 to 15 percent
Color stability, against time	Spectrophotometer, or other colorimeter	Papers, textiles, dyes, paints, etc.	Color, as read by instrument, over an extended period of time. Change with time is noted	With spectrophotometer, as high as 2 percent; with photometers, lower
Internal stress, photoelastic	Polariscope	Glass or plastic objects, transparent	Visible stress pattern, produced by rotation of plane or polarization in stressed areas of specimen	Largely qualitative. In photoelastic stress analysis, variable but low accuracy
Optical rotation	Polarimeter	Organic chemicals	See Chapter IX on Chemical Measurements	See Chapter IX
Index of refraction	Refractometer: Abbe, for solids; dipping, for liquids	Transparent or semi transparent materials	Critical angle of reflection, proportional to index or refraction. Directly graduated instruments. Spectrometer can be used	High; up to 0.02 percent usual, 0.001 percent possible
Color	Colorimeters: Lovibond, Duboscq, Saybolt, or Hellige	Colored, semitransparent or transparent materials	Comparison of color of unknown to that of a standard: Lovibond, glass slides; Saybolt and Hellige, glass disks; Duboscq, variable depth of substandard liquid in comparison cell.	Comparative in general, but there are quantitative systems such as the Munsell
Color	Photoelectric colorimeter	Colored solids or liquids	Usually measures relative transmission through color-separation filters	Variable; may be as high as 2 percent
Color	Spectrophotometer	Solids and liquids	Plots a spectral-color curve for the material	High; reported in I.C.I. terms in general; then perhaps 0.5 to 1.0 percent

TABLE 2:3. DESCRIPTIVE PROPERTIES OF REFINED MATERIALS AND FUELS

Name of Property	*Method or Instrument Name*	*Materials*	*Principle or Criterion Employed*	*Accuracy; other notes*
Flash point, fire point	Flash and fire point tester	Petroleum products, tars, asphalts, etc.	Heating, in open or closed cup, until an applied flame produces either a flash or a flame lasting at least 5 seconds	2 to 5 F. ASTM Spec. D-92, D-93, D-56
Viscosity	Viscosimeter: Saybolt, Ostwald, Hoeppler	Petroleum products, light liquids	Saybolt: flow through orifice; Ostwald: flow through capillary; Hoeppler: fallingball. Time in seconds measured	1 to 3 percent. Temperature is taken at same time as viscosity
Viscosity	Viscosimeter: Stormer, MacMichael	Tars, greases, glues, heavy liquids	Drag on a cylindrical rotor as it is rotated in a bath of fluid	1 to 3 percent. Temperature is taken at same time as viscosity
Specific gravity of gas	Schilling specific gravity apparatus	Natural gas; other gases	Rate of effusion of gas through a small orifice is compared to rate for air	2 to 5 percent. Used principally for field test. In laboratory, gas balance is better. See Table 1:1. 2 to 5 F.
Cloud and pour point	Cloud and pour point apparatus or tester	Petroleum products	Temperature at which material begins to "cloud" because of congelation of dissolved waxes; temperature at which it can be poured at a specified low rate	
Thermal value, or calorific value	Bomb calorimeter, or Junkers gas calorimeter	Fuels	Bomb calorimeter measures amount of heat produced by burning a weighed amount of fuel in a known atmosphere; Junkers calorimeter measures heat produced by burning gas at known rate	Depends largely on technique. 1 percent possible
Flammability	Exposure to flame	Plastics, treated wood, treated textiles, insulating papers, etc.	Measurement of duration of flame resulting, and extent of charred area, after exposure of specimen to standard flame	See various ASTM specifications

rials. These values (elastic limit, modulus of elasticity, tensile and compressive strength, etc.) are usually determined by measuring an applied load and the resulting deformation. These tests have been established as satisfactory for acceptance tests of materials and are in almost universal use. There are other methods, too; in some respects they may be better methods. One such method is the sonic or vibration method for determining the elastic constants of specimens without damaging them, and for determining the damping characteristics of constructional materials. At present, only tentative methods are available for this test.

The terminology in this field is not complete and definite; and some usages are confusing. The term "plasticity," for example, may carry any one of several meanings. To the structural engineer it may mean a characteristic of metal, indicative of the amount of energy absorbed or absorbable; to the foundation engineer it usually refers to a soil condition representing a certain water content; while to a technician testing lime or mortar it refers to the amount of deformation which the material can experience before rupturing. These differences in connotation result from the fact that the name applied to the test refers to the physical behavior observed, not to its significance.

RELATED PHENOMENA AS CRITERIA OF PHYSICAL PROPERTIES

Particularly for field tests, related phenomena rather than specific ones are often employed in determining physical properties. In the Schilling gas-density apparatus, for example, a measured amount of gas is permitted to escape through an orifice of known small size, and the time required is compared to that for air. To the non-technically-trained worker, this appears to be a measure of viscosity rather than of density (as a matter of fact the Saybolt viscosimeter employs such a principle). The difference, of course, lies in the fact that the orifice is small enough to be comparable to the mean free path of the gas molecules. The instrument should perhaps be called an effusiometer (sometimes it is, in the physical-chemistry laboratory) but it is most often used to determine the specific gravity of a gas, and is so named. Another example of the use of a related phenomenon for facilitat-

TABLE 2:4. PHYSICAL PROPERTIES: WORKING

Name of Property	*Method or Instrument Used*	*Materials*	*Principle or Phenomenon Employed*	*Accuracy: other notes*
Porosity	Core porosimeter, liquid absorption method, kerosine test	Coke, brick, stone, insulating materials, plastics, felts, etc.	Increase in weight after immersion in water (or other liquid), reduced to volume	Variable, depending on the technique. 3 per cent may be average. Note: closed pore-space not considered
Permeability to fluids	Penetrometer, Williams	Paper, treated cloth, other thin sheet material	Measurement of volume of water (or other liquid) passing through the material, per unit area, at a known, standardized pressure	Variable; seldom better than 2 percent
Permeability to gases and vapors	Diffusimeter	Thin sheet materials	Measurement of volume of gas or vapor passing per unit area per unit time	Variable; usually not high. Techniques control accuracy
Permeability to water, of bituminous materials	Float test	Bituminous materials, for roofs and pavements	Application of heat, with a small applied head of water; time until water penetrates material taken as measure of consistency	Quantitative accuracy low but a valuable empirical test. See ASTM Cpec. D-139
(Permeability to fluids in general: see Table 1:1)				
Particle size*	Hydrometer: mechanical analysis method	Soils in suspension	Specific gravity of suspension indicates weight of material suspended; settling time indicates particle size of particles	2 percent. See ASTM Spec. D 422
Particle size*	Elutriator, dry or wet	Any powdered material, 300 mesh or finer	Air (or water) current employed to seperate powdered material into size groups; the particle size in each group is determined microscopically. Many modifications.	Can be as high as 1 percent; usually is about 3 percent.[4] Useful for large-scale applications
Particle size* specific surface	Turbidimeter, Wagner or Klein	Fine particles, particularly Portland cement	Fine powdered material is suspended in a light oil; turbidity produced is a measure of the specific surface of the material	2 to 10 percent. See ASTM Spec. C-115
Resistance to abrasion	Abrader or abradimeter	Rubber products, cloth, leather	Abrasive surface rubbed against specimen; change in weight or thickness measured	See ASTM Spec. D 394
Resistance to abrasion, mar resistance	Abrader	Transparent plastics	Granulated abrasive poured continuously against surface. Loss of gloss measured	See ASTM Spec. D 673
Resistance to abrasion	Deval machine	Gravel or aggregate	Tumbled with steel cubes; amount of fine material produced taken as measure of abrasive damage	2 to 15 percent
Plastic properties	Proctor needle	Soil	Relation between plasticity and moisture content; often determined in laboratory and used in field as a quick test	Moderate accuracy
Plastic properties	Liquid-limit tester	Soil	Plasticity indicated in terms of resistance to flow under mild mechanical shock	Almost entirely empirical, but very useful. See ASTM Spec. D 423, AASHO Spec. T 89
Plasticity	Emley plasticimeter	Lime putty, mortars, etc.	Measurement of drag on a rotating table as it presses a sample against a fixed surface	Technique extremely important; data comparative
Plasticity	Mobilometer, Gardner	Paints, varnishes, glues, cosmetics, etc.	Rate of fall of a weighted plunger in the container of material	Empirical test, accuracy moderate, 5 to 15 percent
Sticky-point	Olmstead sticky-point tester	Soils	Determination of moisture content at which soil mixture just fails to stick to polished surface moving at known speed	Empirical test, of considerable practical value. Comparative accuracy moderate, 5 to 15 percent
Plasticity	Vicat apparatus	Cement mixtures, lime, gypsum, soils, mortar, etc.	Determine "consistency" by depth to which known weights drive plungers into plastic material	Empirical test. Moderate accuracy, 3 to 10 percent
Moisture content, surface moisture, etc.	Loss in weight	Any material not injured by temperatures of 250 F. for several hours.	Loss in weight (percent) after heating to constant weight	1 to 2 percent. Conditions must fit material
Moisture content	Electrical moisture meters	Wood, grain, fibers	Change in resistivity or in specific inductive capacity with moisture content	Less accurate than loss-of-weight method, but quite rapid in use. 2 to 5 percent
(Moisture content of soils: see Plastic Properties, above)				
Vapor pressure	Reid bomb	Light liquids, particularly petroleum products	Measurement of gas or vapor pressure by Bourdon-type gage, at various temperatures	Moderate, 2 to 5 percent

* In these methods, the size classification is not a function of particle dimensions only (as with sieves) but also of shape, density, surface texture, etc.

ing tests for field applications is the Proctor soil-plasticity needle, used for quick field determination of soil moisture—after being calibrated in the laboratory by plotting curves of plasticity *versus* moisture content.

Some physical properties must still be determined by the techniques of the physics laboratory, either because there has not been sufficient demand for special instrumentation or because no suitable method of attack has been devised. The specific heat of materials can usually be determined accurately only by a calorimetric method. In such a method the technique is nearly as important as the instrument; the special advantages of some of the specialized instruments are not available. Such methods are described in the textbooks.

In contrast to these "basic" physical methods are methods such as the specialized ones used for determining refractive index. This property, defined as the ratio of the velocity of light in air to its velocity in the specimen material, is measured by a refractometer—operating on a related physical phenomenon. The available instruments are extremely easy to use, and also extremely accurate; a highly-trained operator is not needed. The same is true of polarimeters.

It is necessary to make a distinction between properties and characteristics of *materials*, and properties and characteristics of *objects*. The final inspection of a steel piston-pin, for example, will involve a dimensional measurement; the dimension is a characteristic of the object, but not of the material. The hardness of the metal, however, is a property of the material. Dimensional inspection is not considered in any of the categories described here; it is discussed in Chapter XII. The final inspection of a ball-bearing assembly, on the other hand, often includes a running test to determine its smoothness and quietness of operation. These are qualities of the assembly that govern its satisfactory performance in service. There are a number of such methods, most of them quite specialized.

Service and Environmental Tests

An entire category of tests, intended to evaluate those properties of materials governing their service life, is described as "service and environmental" tests. They are performed under conditions similar to normal service conditions, but usually more severe in some respect. Examples are the freezing-and-thawing tests for masonry and concrete, fade tests for textiles and paints, and abrasion tests for fabrics, plastics, and rubber products. Somewhat comparable to these are the fatigue tests of structural metals, although this property is intimately related to the "strength" qualities of metals, while the "environmental test" usually is designed to disclose change of appearance as much as change in strength.

There are a number of standardized forms of tests in this category; there are many more specialized tests not widely enough used to be considered standard.

Properties of Appearance and Color

For many years, the color and texture of certain materials have been considered the best practical criteria of their quality; it is only in the last decade or two that techniques for evaluating these qualities have been devised and systematized. There are now available a number of quite highly spe-

TABLE 2:5. MECHANICAL-THERMAL PROPERTIES

Name of Property	*Method or Instrument Used*	*Materials*	*Principle or Phenomenon Employed*	
Spalling resistance	Furnace, optical pyrometer	Refractory materials	Materials exposed to high temperatures for test duration; damage (cracking, loss of material, warping, etc.) noted	See ASTM Spec. C-38
Arc resistance	Arc resistance apparatus	Electrical insulating materials	High-voltage arc is applied to surface of material; time to form a conducting path is noted	See ASTM Spec. D-495
(Melting points: see **Table 1:4**)				
Softening point	Ball and **ring test**	Bituminous materials	Softening point is the temperature at which a steel ball will drop through a ring filled with the test material	Plus or minus 0.9 F.
Softening point	Cube-in water test	Pitch, tar	Cube of material is suspended in water on hook; temperature at which it drops to the bottom noted	Plus or minus 1.0 F.
(Penetration of liquid under heat: see Float Test, Table 2:4)				
Decalescence and recalescence points	Thermal anaylsis method	Steel	Test consists of recording rate of change of temperature of steel sample versus rate of change of furnace. Inflection points in this curve indicate transformation points in steel	Test is largely qualitative. Temperatures can be measured to 2 to 5 F.

GROUP 3: SERVICE PROPERTIES OF MATERIALS

TABLE 3:1. SERVICE PROPERTIES OF MATERIALS

Property	*Method or Instrument*	*Materials*	*Principle or Criterion Employed*	*Notes*
Fatigue of materials	Rotating-beam fatigue machine, axial-type fatigue machine, etc.	Metals, plastics	Number of cycles to failure at known load	Final datum is "fatigue strength" and is indicative of probable life in service
Creep of materials	Creep-test apparatus	Metals, plastics	Rate of extension under known constant load, extending over periods of days or months. Temperature is usually controlled	Final datum indicates probable change of dimensions during service life of parts
Accelerated aging characteristics:				
of gasoline, grease, etc.	Potential gum apparatus	Greases, gasoline	Formation of gum, or drop in oxygen pressure in apparatus	Stability life of material is usually comparable to the initial slow rate of oxygen absorption
of brick and concrete	Freezing-and-thawing tests	Brick, concrete	Successive cycles of freezing and thawing with loss in weight and mechanical damage noted	Empirical test, but of proved value
of non-ferrous metals	Salt-spray test	Non-ferrous metals	Specimens exposed to intermittent or to continuous salt-water spray. Effects on specimens noted in report	Test gives comparative data as to resistance of materials. Not necessarily indicative of service life
of electrical heater-element wire	Accelerated aging apparatus	Electrical heater wire	Tests consist of intermittent but repeated applications of electric current to the wire, to determine oxidation characteristics and dimensional changes	Comparative test, but fairly indicative of service life in ordinary applications
of paint, paper, glass, textiles, etc.	Carbon-arc weathering unit	**Textiles, paint, paper, glass, decorative materials.**	Exposure to light from carbon-arc unit, to water sprays, etc., to simulate weather conditions	Comparative test, but fairly indicative of service life in ordinary applications

cialized instruments, such as turbidimeters, spectrophotometers, electrocolorimeters, electrofluorimeters and the like, whose development is due in part to improved techniques, and in part to an improved understanding of the nature of color and its effects. Optical, photometric, and colorimetric methods are available for many applications, including filter classification, measurement of surface smoothness, of particle size, of specific surface, and many biological and physiological measurements. Methods of this kind are in general quite highly specialized; no detailed description can be given here.

Many of the older methods, like the Lovibond colorimeter, the Saybolt chromometer, and other visual-comparison methods are still in use, and will continue in use for years. Such instruments, employing color slides, are rather sensitive, but subject to error from operator error or fatigue, and to change of calibration from aging of the color slides. It is entirely possible to convert the data from these instruments, or any other color, to a numerical value, through the use of the spectrophotometer and the system recommended by the International Commission on Illlumination. Such a numerical value is permanent.

AVAILABLE STANDARD METHODS

Many of the technical societies have prepared listings of standards, of standard methods and of techniques. The American Society for Testing Materials is perhaps the largest of these, providing standard methods on most industrial product testing. Others are the American Association of State Highway Officials, the United States Department of Commerce, the Department of Agriculture, the Bureau of Mines, the American Chemical Society, the Association of Official Agricultural Chemists, and the American Society of Brewing Chemists. So far as is possible, these organizations have collaborated on their recommendations. Some of the items listed in the attached tables carry references to ASTM or AASHO standard specifications.

TABLES

The tables which accompany this discussion are not and cannot be complete. They are representative of the most widely used methods for determining the properties found most useful in science and in industry.

Duplication of items in the tables of this Chapter and of items in the several Chapters of this Handbook, is inevitable. It has been kept to a minimum.

The organization of these tables follows the three points listed in the paragraphs on "Engineering *versus* Laboratory Properties." The first group of properties comprises identification or acceptance tests; the second, properties of refined products, of building materials, and the like; and the third, service or environmental tests of properties. Although in this brief tabular form it is quite impossible to give any detail on any method, for many items there are references to ASTM methods, in which detail can be found; in most of the others there is sufficient information to guide the reader directly to sources of information.

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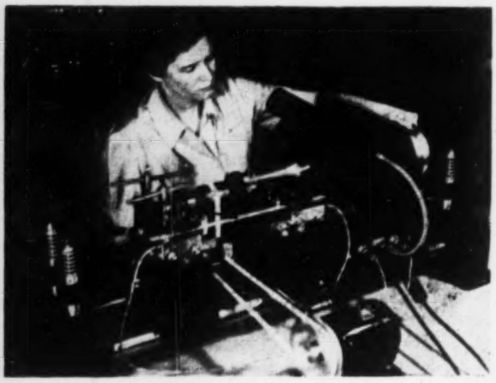

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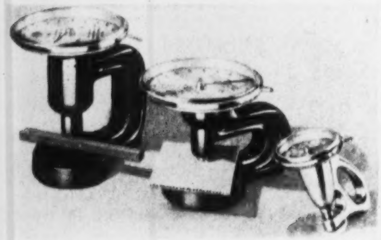

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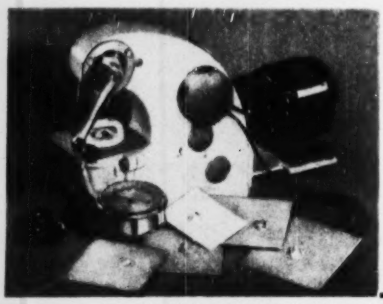

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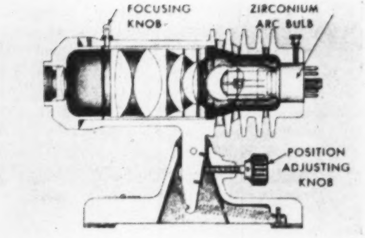

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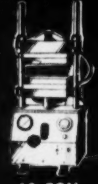

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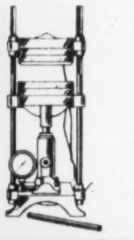

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CHAPTER VIII
SPEED MEASUREMENT AND CONTROL
By M. F. BEHAR

1. General

THIS chapter discusses the measurement and control of the linear and rotational speed of mechanical objects. (Measurement of fluid flow-rate is treated in Chapter V.) When the DIRECTION of motion is considered, distance divided by time is not speed but VELOCITY.

The forms of speed considered are:

(I) The number of regularly recurrent events per time interval; i.e. *frequency*, generally expressed in cycles per second or strokes per minute; or *rate*, as in radioactivity measurement.

(II) *Rotational speed*, expressed in revolutions per minute (rpm.) or radians per second.

(III) *Linear speed*, expressed in feet per minute (fpm.), miles per hour (mph.), etc.

(IV) *Differential speed* or speed ratio, such as the textile industry employs to indicate percent stretch during sizing.

(V) *Acceleration*, or the rate of change of speed, expressed as miles per hour per second, feet per second per second (ft./sec.^{2}), etc.

Table I, listing the characteristics of industrial speed-measuring instruments, has been devised as a rapid means of ascertaining characteristics of the various available equipment and methods.

TABLE I—SPEED MEASURING INSTRUMENTS

Class	*Type*	*Range Limits*	*Accuracy*	*Temp. Error*	*Form of Speed Measured*	*Availability (See Notes)*	*Other Characteristics (See Notes)*
COUNTERS							
Mechanical	Circular Dial	*counts/min.*					
	Direct Geared—Hand	0-2000	Abs. (dd)	None	I, II, III	Ind.	Pv-Av-S-Sd
	Direct Geared—Connected	100-3000	Abs. (dd)	None	I, II, III	Ind.	Pv-Av-S-Sd
	Cyclometer						
	Direct Drive—Connected	0-2000	Abs. (dd)	None	I, II, III	Ind.	Pv-Av-S-Sd
	Clutch—Hand	100-2500	Abs. (dd)	None	I, II, III	Ind.	Pv-Av-S-Sd
	Ratchet—Connected	0-800	Abs. (dd)	None	I, II, III	Ind.	Pv-Av-S-Sd
	Ratchet—Hand	——	Abs. (dd)	None	I, II, III	Ind.	Pv-Av-S-Sd
Electrical	Ratchet—Electromagnetic	0-12,000	Abs.	None	I, II	Ind.	Pv-Av-S-Sd
	Cam Operated Circuit	——	Abs.	None	I, II	Ind.	Pv-Av-S-Sd
Electronic	Electronic Circuit	*cps.* 10,000,000	0.05%	None	I, II	Ind.-RR	Pe-Av-S-Sd
Electric Impulse	Rotation actuated Switch	1-100,000	0.25-1%	None	II	Ind.-Rec.	Inf-Inst-Re-RR-Sd
Tachoscope	Electrically Started	*rpm.* 0-30,000	dt	None	II, III	Ind.	Pv-Av-S-Sd
	Mechanically Started	0-30,000	dt	None	II, III	Ind.	Pv-Av-S-Sd
	Electric Start—Electronic Count	0-60,000	±0.05%	None	I, II, III	Ind.	Pe-Av-S-Sd
Speed Indicator	Mech. Period Control (3 Sec)	400-20,000	±0.25%	None	II, III	Ind.	Pv-Av-S
	Mech. Period Control (6 Sec)	200,-20,000	±0.25%	None	II, III	Ind.	Pv-Av-S
	Electronic	10,000,000	±0.008%	None	II, III	Ind.-RR	Pe-Av-S-Sd
TACHOMETER							
Chronometric	Integrating	100-10,000		None	II, III	Ind.-Rec	Pv-Co-Av
	Conjugating	100-5,000		None	II, III	Ind.-Rec	Pv-Co-Av
	Electronic	10,000,000	±0.025%	None	II	Ind.-RR	Pe-Co-Av-Sd
Centrifugal Weight	Flyball	100-40,000	10 Rev	Slight	II, III	Ind.-Rec.-C	Pv (Gr) & Int, Inst-Co-Fr-Pn-Sp (Pred)
	Cross Pendulum	30-48,000	20 Rev	Negligible	II, III	Ind.-Rec	Inf-Inst-Co-Fr-Sp
	Tilting Ring	25-30,000	25 Rev	Slight	II, III	Ind.-Rec	Inf-Inst-Co-Pn-Sp
	Ball & Cup	Narrow	0.5%	Unaffect	II, III	Ind.	Pv-Inst-Co-Pn-Sd
Fluid Displacement	Liquid Cup (Cent.)	Narrow	——	Very Little	II, III	Ind.-RR	Pv-Co-Pn-Inst
	U-Tube (Cent.)	10-4,000	1%	Very Little	II, III	Ind.-Rec	Inf-Co-Pn-Inst.
	Liquid Pump (Cent.)	Narrow	0.1%	Very Little	II, IV	Ind.-RR	Inf-Co-Pn(Ind Device)-Inst.
	Liquid Pump (Positive)	Commercial	——	Yes	II, IV	Ind-Rec-RR-C	Inf-Co-Pn(Ind Device)-Inst.
	Pneumatic Pump (Cent.)	Narrow	1%	Yes	II, IV	Ind.-Rec-RR	Inf-Co-Inst-Fr
Electric	D-c. Generator	0-5,000	±1% F.S.	Negligible	II, III, IV	Ind-Rec-RR-C	Inf-Co-Inst-M
	A-c. Generator	0-15,000	±1% F.S.	None	II, III, IV	Ind-Rec-RR-C	Inf-Co-Inst-M
	A-c. Gen. (Saturable Core)	——	±1% F.S.	——	II	Ind.-RR	Inf-Co-Inst-M
Capacitor	Oscillating Contacts	200-10,000	±1% F.S.	None	II, III	Ind.-Rec.	Pe-Co-Inst
Magnetic Drag	Cup or Disk	0-2,000	10%	Comp.	II	Ind.	Inf-Co-Inst-Fr-M-Sp
	Electric Transmitting	0-4,500	0.1% F.S.	Comp.	II	Ind.	Inf-Co-Inst-M-Sp-Fr
Viscous Drag	Cup Scale	Narrow	Poor	Yes	II	Ind.	Inf-Co-Inst-Fr-T-Sp
Inertia	Pawl & Wheel	*counts/min.* 200-2,000	Poor	None	II	Ind.	Inf-Co-Inst-Fr
FREQUENCY		*cps.*					
Electrical Frequency	Reed	15-1500	0.2% Rated	0.4%/50C.	I	Ind.	Pv-Co
	Induction Disk	Narrow	2%	Yes	I	Ind.-RR	Inf-Co-Fr-Pn-Inst.
Repetition Frequency	Bridge (Dynamometer)	20-65	0.2 Cycle	Comp.	I	Ind.-RR	Inf-Co-Fr-Pn-Inst.
	Bridge (Null)	22-70	0.2 Cycle	Comp.	I	Ind-Rec-RR-C	Inf-Co-Inst.
	Moving Vane	20-65	0.2 Cycle	——	I	Ind.-RR	Inf-Co-Inst-Fr-Pn
	Electronic	5 cps-50 Mc.	2% F. S.	Negligible	I, II, III	Ind.-RR	Pe-Co-Inst.
Vibration Frequency	Reed	900-60,000	0.2% Rated Freq.	0.4%/50C.	I	Ind.	Pv-Co
	Tachoscope (Pendulum)						
STROBOSCOPE							
Interrupted Sight	Revolving Drum or Disk	500-32,000	—(dd)	None	II	Ind.	Pv-Co-Inst
Interrupted Light	Revolving Mirror or Disk	0-33,000	—(dd)	None	II	Ind.	Pv-Co-Inst
Intermittent Light	Flash Tube	32-4000	0.05%	None	II, III	Ind.-RR	Pe-Co-Inst-Sd
CHRONOGRAPH	Magnetic	——	——	None	II, III	Rec-RR	Pv-Av-Fr-Pn
OSCILLOGRAPH	Galvanometer	——	——		II, III	Rec-Ind-RR	Pv-Co-Av-Pv-Sd-Pn
	Cathode Ray	30-UHF	——	Comp.	II, III	Ind.-RR	Pe-Co-Inst.

Standards. No matter what its form, a speed is a time rate, i.e., a ratio; the ultimate reference standards are two intangibles: Number and Time Interval.*

A method of measuring speed which is based on (1) *counting* a number of revolutions, cycles, or other events, and (2) *measuring* a time interval, may be classified as a *direct* or *positive* or *primary* method.

In addition, instruments are said to be "primary" when they can be built and calibrated without being compared against standards. Thus, a flyball tachometer depending only on its geometry and on gravity (not on a spring) could be classified as "primary"—but only in theory because of imperfections.

All other methods are *indirect, inferential* or *secondary*: the instruments do not measure "speed"; they only measure some effect of speed, such as a voltage, a pressure, a spring deflection, etc.

Theoretically, the primary methods are the ones capable of the highest accuracy. Practically, the most accurate commercially-available standards are "secondary." They are fixed-frequency standards in the forms of oscillating crystals or tuning-forks in temperature-controlled housings. Guaranteed accuracies of "parts per million" are common.

The new International Standard of both Time and Frequency will probably be an absorption line of one of the molecules that exhibit transitions in the microwave radio spectrum. Example, the ammonia molecule, used since 1949 in the "atomic clock" of the National Bureau of Standards.

In like manner the term "instantaneous" is generally used in a relative sense: an "instantaneous" speed is often an average speed measured during a sampling period which is "extremely short" in relation to others.

2. COUNTERS

It often is said that a counter is either absolutely accurate or utterly unreliable—"either in good order or no good." This is axiomatic, but it is true only with respect to events which are *positively* countable because each event is (a) *distinct* and (b) *indivisible.*

(a) A *distinct* or "unambiguous" event is one which the counter cannot confuse with another event. When two or more events are nearly simultaneous, the counter may skip all but one, or otherwise fail to function as intended. Each type of counter has a minimum resolving time, or maximum counting speed.

(b) An *indivisible* event is one which is not resolvable into lesser events, smaller angles, etc. Thus, a count of "10" shaft revolutions which is "absolutely" accurate because it is the count of ten distinct pulses from a snap switch can be reported as "exactly ten pulses" but it should not be reported as "exactly ten revolutions" (which implies exactly 3600.00 degrees). The same is true of electronic counters which count the complete cycles of wave phenomena.

A safe rule to follow, even with absolutely accurate counters and accessories, is to take it for granted that the irreducible error of counting is plus or minus one count for each sampling period NO MATTER WHAT COUNTING METHOD IS USED; and to write "±1" after every reading.

Another good rule is to make sure that the *time* measurement is sufficiently accurate. In practice this usually means: For one percent minimum allowable total error, the sampling period must be two hundred times the starting or stopping uncertainty (100 times starting PLUS stopping uncertainties).

Hand Counters.—There are two types of hand counters. The *geared type* is the familiar type in which the dial is rotated by a worm gear on a spindle, as shown in Fig. 1. The large outer dial is usually graduated into 100 lines, each one of which represents one revolution of the spindle. The small dial can have 50 lines, each representing one revolution of the outer dial.

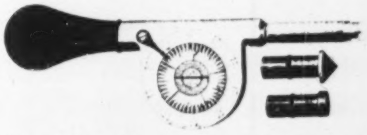

Fig. 1. Direct-drive worm-geared hand counter.

The *cyclometer type* of hand counter has a direct-reading cyclometer register consisting of (usually) four digital drums. The first digital drum is rotated one tenth revolution for one revolution of the external spindle. In completing one revolution, this drum moves the second drum one tenth revolution. Similarly, the third drum counts tens; the fourth, hundreds. A clutch allows the spindle to run free until the operator starts the reading by pushing the counter against the end of the rotating shaft.

Continuous Counters.—Designed for permanent installation, these counters

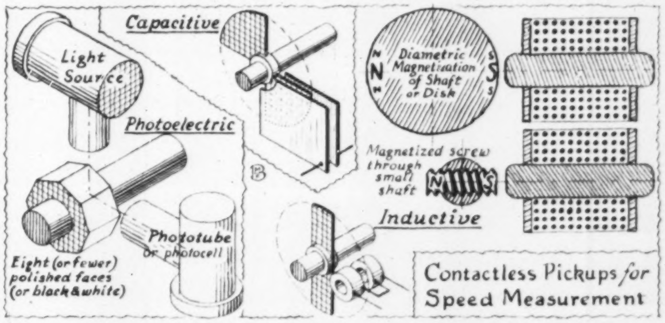
Capacitive
Light Source
Photoelectric
Phototube or photocell
Eight (or fewer) polished faces (or black & white)
Diametric Magnetization of Shaft or Disk
N
S
Magnetized screw through small shaft
Inductive
Contactless Pickups for Speed Measurement

Fig. 2. Types of electrical-output pickups for counters and tachometers.

NOTES FOR TABLE I

Forms of speed measured—The Roman numerals refer to the five forms of speed described in this section.

dd—Depends on drive or operator technique. Examples, allowing counter to slip on end of shaft being counted or losing stroboscopic effect while using the stroboscope.

dt—Depends on time period. Instruments thus marked require careful consideration of the sampling period to obtain the desired accuracy.

Ind—Available as an indicator.

Rec—Available as a recorder.

RR—Remote reading systems available (beyond the limits of flexible shaft). This classification is given to most electrical instruments and to instruments capable of transmitting an air pressure proportional to the speed indication.

C—Can be used in a control system. These instruments contain control features within the instrument itself, or supply a signal or command which is used in a control system.

Pv—Positive measurement principle (Gr when gravity, or no spring). Positive speed-measurement methods and instruments are those which integrate or conjugate "time" and "number" or "time and distance," as well as "geometrical" speed-measuring instruments wholly independent of the action of springs.

Pe—Positive electric circuit. This classification covers instruments utilizing the laws of electricity in such manner that a count of events is divided by a direct measurement of time.

Inf—Inferential measurement principle. This classification includes all instruments not of the aforementioned types. It includes all types dependent on springs, magnetic forces, viscosities, etc.

S—Gives single reading each time used.

Co—Continuously measures.

Av—Measures average speed over time period. Most positive-measurement methods require an appreciable sampling period in which to accumulate a count. When the scale is calibrated in an instantaneous unit based on this period and count, the indications must be an average.

Inst—Measures speed or frequency instantaneously. Mist inferential instruments give instantaneous readings because they depend on a balance of forces to position the measuring element.

Sd—Suitable for use as a plant standard.

Sp—Measurement based on spring tension.

T—Temperature fluctuations affect accuracy. Effort has been made to determine and state the magnitude of the temperature effect. Some instruments are variably affected and are so indicated.

Fr—Friction affects accuracy. This includes instruments in which a small variable torque is used to position the indicating element.

Pn—Position affects accuracy. Many instruments must be operated in a given position for highest accuracy. Some of these instruments have a spirit level built into the frame or case of the instrument.

M—Magnetic field and electrical conditions affect accuracy. This classification has only been used when the instrument is not designed with compensation.

Range Limits—The figures given in this column show the limits of operation for instruments of a given class and type. The figures do not imply that this range can be handled with one instrument—if one is designed for 0 to 600 rpm., whereas another model is from 400 to 800 rpm., the maximum to minimum for the class of instruments is 0 to 800 rpm. The limits are those obtained by internal gearing or circuit values rather than external gear reducers and transformers.

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*However the industrial reference standards of Time at the National Bureau of Standards are signals easily accessible by means of a radio receiver.

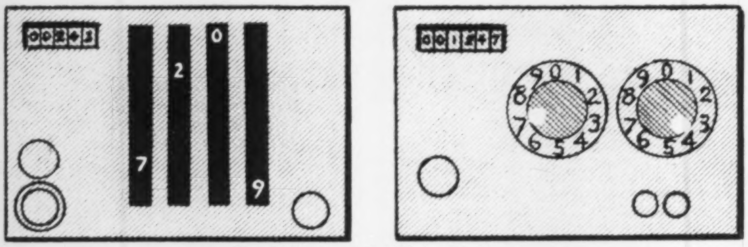

Fig. 3. Types of electronic counters.

are generally built for severe industrial service. Models are available for panel or wall mounting. Predetermined counters, printing counters, shift pick counters, and others are used widely in industry.

Electromechanical Counters.—In their simplest form, these consist of a cyclometer register advanced by a ratchet operated by a solenoid or other electrical device which, in turn, is operated by a remote contact-making and -braking device, such as a switch or relay, whose function is to supply distinct on-and-off *pulses*. For textile-machine shafts and other relatively delicate parts which must not actuate contactors, the pulses can originate in photoelectric, capacitive, or inductive pickups (as sketched in Fig. 2) and, if necessary, actuate electrical relays producing sharp on-off pulses of the voltage required by the electromechanical counter.

Electronic Counters.—These were first developed to supply the needs of nucleonic research, such as counting random events separated by intervals from hundreds of microseconds down to a fraction of a microsecond. Of the commercial types, two are suitable for general industrial applications. One indicates by rows or columns of ten glow lamps each, as sketched in Fig. 3A; the other makes use of decade counter tubes, as sketched in Fig. 3 B. In each of these types the units device causes an impulse to actuate the tens device every ten counts, and so on. (Each of these types is available in models in which a cyclometer register is added, whose digits read the higher powers of ten.)

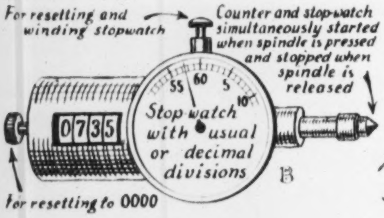
For resetting and winding stopwatch
Counter and stop-watch simultaneously started when spindle is pressed and stopped when spindle is released
55
60
5
10
0735
Stop watch with usual or decimal divisions
B
For resetting to 0000

Fig. 4. Manual Tachoscope.

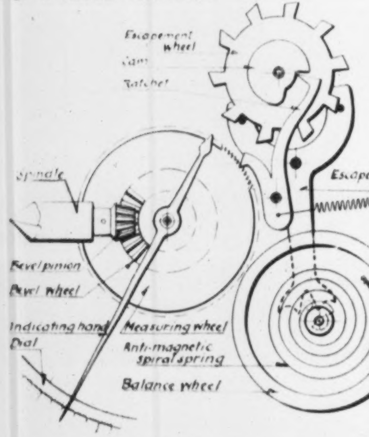

Fig. 5. Speed-indicator type of tachoscope.

3. TACHOSCOPES

A tachoscope combines a counter and a timepiece. In *manual* tachoscopes, the counter and timepiece are mounted side-by-side. A push-button starts the timepiece at the same time that the counter starts to register. (Fig. 4).

The *speed-indicator* type of tachoscope, shown in Fig. 5, has a revolution counter controlled by an automatic timer. Synchronization of the two units is done by a cam mounted on the escapement wheel and ratchet. When the spindle is revolved, the ratchet frees the measuring wheel for a definite time interval, at the end of which the ratchet locks the measuring wheel. The dial is calibrated directly in speed (rpm.).

4. CHRONOMETRIC TACHOMETERS

The chronometric tachometer is similar in principle to the speed-indicator tachoscope, but differs in the important respect that it repeats automatically.

Chronometric tachometers which are constructed like speed indicators can be called integrating; those which successively conjugate, or make contact with, actuated members can be called conjugating. In all types the number of revolutions of the primary shaft is counted during a definite time interval.

A typical conjugating-type chronometer tachometer is shown in Fig. 6. The gear A at the bottom is rotated by a chronometric escapement. It rotates through 120 degrees in one second, or through one revolution in three seconds. As it rotates, it carries three timing sectors M_1, M_2, and M_3 around with it. Each sector is in contact with the rotating shaft to be measured through the measuring pinion *O* for exactly one second. As each sector is free to move vertically on spline shaft W, each sector is raised to a height which depends on the speed of measuring pinion *O*. When the sector disengages the measuring pinion, it is kept in its elevated position by detention roller P. Collar R, attached to indicator pointer Z, rests on each sector as the sector comes into position under the collar. Thus the pointer is automatically reset every second to a position which indicates the number of counts registered by one of the sectors for the previous second. The pointer does not drop to zero between settings.

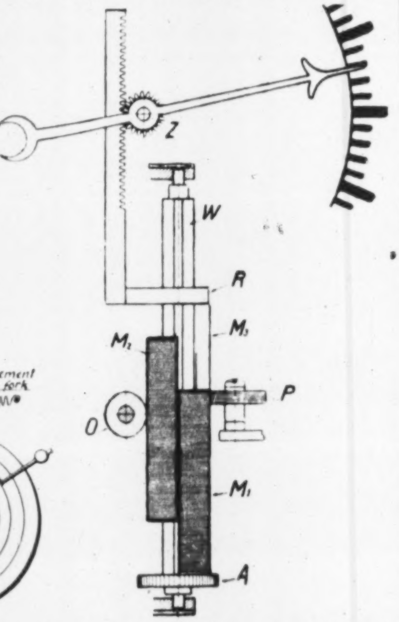

Fig. 6. Conjugating-type chronometric tachometer.

Electrical Chronometric Tachometers.—Strictly speaking, these are mechanoelectrical instruments, employing electricity for remote actuation of counter and for clock drive.

One type (trade-name "Chrono-Tachometer") is widely used for calibrating aircraft (and other) tachometers. It comprises a counter readable to 0.1 revolution and a special synchronous clock with its fastest hand reading to thousandths of a minute. The clock is driven from the a-c. line in most industrial districts, but can be driven from a frequency standard. Operation is automatic.

Another type independent of manual operation is a recorder with a fixed sampling period during which a dry stylus scratches through a wax coating to produce a line whose length represents the count of revolutions, then flies back to zero. The usual cycle is $37\frac{1}{2}$ seconds, comprising a 30-second sampling period and a $7\frac{1}{2}$-second interval. See Fig. 7.

Electronic Chronometric Tachometers.—These combine an electronic counter (see above under "Counters") with an automatic timer and with an automatic repeater whereby the previous count is erased and the new count displayed on the glow-lamps or decade

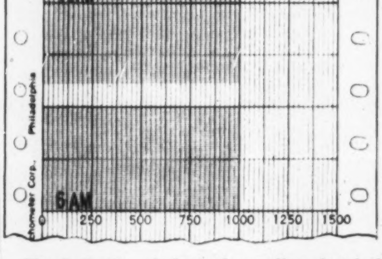

Fig. 7. Section of chart of recording electrical chronometric tachometer. The machine to which the recorder is connected started at 6 a.m., ran steadily at 1000 rpm. until 6:30 when it was shut down for seven minutes, then ran at 1000 rpm. until 7:05 when the speed was increased to 1125 rpm.

tubes. They are seldom called "chronometric tachometers," having been given various names while they were still wartime fission-bomb project secrets. Today their commonest generic designation seems to be "frequency counters." Moreover, the frequencies which most of these instruments are designed to count cycle-by-cycle or pulse-by-pulse are seldom the commercial frequencies but the radio frequencies. Fig. 8 is a block diagram of a simple "frequency counter" for the MF range (300 kc. to 3 Mc.). The sampling period is controlled by means of a crystal oscillator. Its duration is selected by connecting one of the frequency dividers in the "Dividers" cabinet. Thus it is possible to obtain unusually long sampling periods (seconds instead of milliseconds) and some makers are prepared to supply the required components. Most of the commercial instruments are not so simple; they include deflection-type (non-counting) frequency meters. See Section 8.

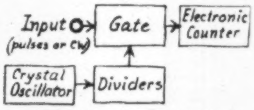

Fig. 8. Block diagram of electronic chronometric tachometer. (Commercial models are known as "Frequency Counters," "Events-per-unit-time meters," etc.)

5. PUMP-TYPE TACHOMETERS

Pneumatic and hydraulic pumps, driven directly by engines, turbines, etc., have been used as tachometers for many years in power plants, where many operators still favor them as "reliable machines, not delicate instruments." Most pneumatic types are modified blowers, discharging through restrictions and thereby producing a pressure proportional to the square of the speed. Most hydraulic types are positive-displacement rotary pumps, sucking oil from a reservoir and discharging it through a restriction into the reservoir, the pressure in back of the restriction likewise being the square of the speed.

The enduring popularity of pump-type tachometers is largely due to the use of rugged pressure gages as indicators, recorders and control-system command-elements.

6. CENTRIFUGAL TACHOMETERS

Flyball types.—There are two basic types of these—gravity loaded and spring loaded. A typical spring-loaded flyball-tachometer movement is shown in Fig. 9. Spring loading increases the speed of response to variations in instantaneous speed. Flyball tachometers and governors should not be used near the zero or maximum of the range.

Cross-pendulum type.—The cross-pendulum type of tachometer is a centrifugal-force device which uses, instead of two flyballs, four weights at the ends of two crossed arms. When rotating, the weights tend to assume a position perpendicular to the rotating spindle. The use of four weights minimizes vibration and also makes the rotating unit independent of horizontal and vertical orientation.

Tilting-ring type.—Tilting-type centrifugal-weight tachometers include not only the ring-pendulum type but also any centrifugal tachometer with a single crossbar weighted at its end and pivoted at its center. Various unbalanced-type centrifugal tachometers, therefore, are tilting types.

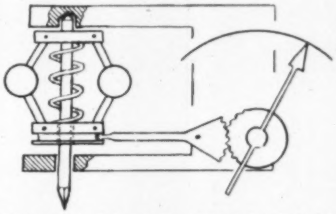

Fig. 9. Principle of the flyball hand tachometer. The scale is non-linear even with a spring that obeys Hooke's Law.

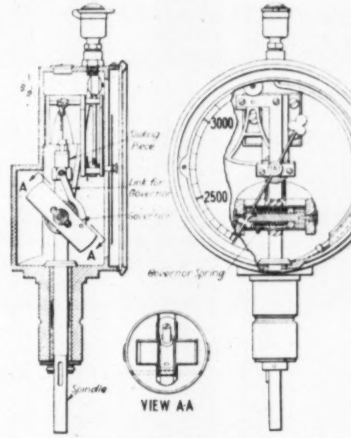

Fig. 10. Tilting-ring tachometer.

7. ELECTRIC TACHOMETERS

The electric tachometers here considered are not frequency meters; they are essentially d-c. or a-c. generators connected to voltmeters, which indicate the output of the generators. Their principal characteristics are as follows:

(1) Electric tachometers measure speed continuously.

(2) They usually are not capable of indicating and recording rapid fluctuations, but can be damped to smooth out rapid fluctuations.

(3) The measurement of speed with the electric tachometer is inferential, but the relation between speed and the generator response is usually a straight-line relation. In such systems, accuracy and other measuring properties depend largely on the indicating instrument itself.

(4) The linear characteristics of most electric tachometers make possible uniformly-graduated recorder charts.

(5) The generators impose a load on the shafts whose speeds are measured; they must not be used where this load would be a source of error.

(6) The indicating instruments are electrical instruments obtainable in many standard forms and sizes.

(7) It is possible to connect a plurality of instruments to one generator and to change instruments at will.

(8) The indicators can be located at a distance from the generators.

(9) The direction of rotation is immaterial in most industrial types.

(10) Repairs and replacements usually can be made readily on the unit parts of an electric-tachometer system.

D-c. generator.—Fig. 11 shows a d-c. generator for use in a tachometer. The output is a pulsating d-c. voltage, which is indicated on a d-c. voltmeter calibrated in speed units. For accuracy, the output voltage can be applied to a high resistance with taps, and the measurement can be made on a null-type potentiometer.

A-c. generator.—The operation of one type of a-c. tachometer is shown in Fig. 12. The magnets send flux through the stator coils. The rotor is simply a laminated slotted cylinder. As the teeth of the rotor pass the pole pieces attached to the laminated stator, the reluctance of the air gap between rotor and stator varies. This varies the flux through the stator coil and induces an a-c. output voltage, which is proportional to the speed of rotation of the rotor.

Another method uses a stator coil with multiple pole pieces, as in Fig. 12. However, instead of a fixed magnet and laminated rotor, the rotor is a permanent magnet which induces voltage in the stator coil as it passes the pole pieces, somewhat as sketched in Fig. 2. Rotors and stators are laminated to reduce eddy currents.

The drag-cup a-c. tachometer (not to be confused with the magnetic-drag tachometer described in the next section) is somewhat similar in principle, but is mechanically the reverse of Fig. 12. The stator is the innermost mem-

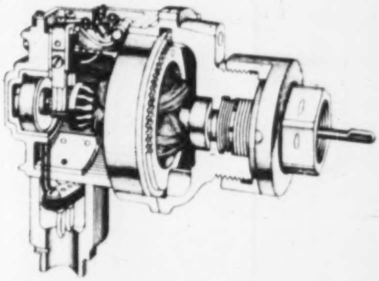

Fig. 11. D-c. generator of special design for tachometric service.

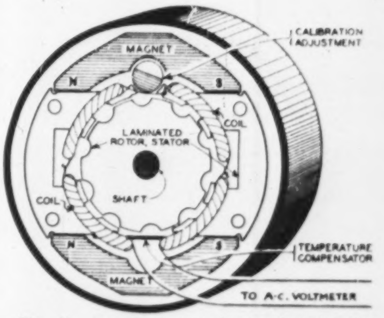

Fig. 12. A-c. generator of special design for tachometric service.

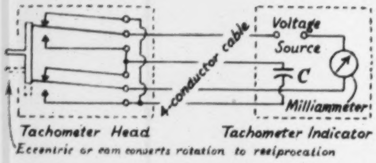
Voltage
Source
C
Milliammeter
4-conductor cable
Tachometer Head
Tachometer Indicator
Eccentric or cam converts rotation to reciprocation

Fig. 13. Capacitor charge-and-discharge type of tachometer.

ber; it is inside a rotating thin-wall cylinder, and the outermost member is a cylindrical housing which completes the magnetic circuit. When one phase of the stator is energized from a constant-amplitude constant-frequency voltage source, the other phase of the stator yields a voltage proportional to the speed at which the cup is driven. The design saves weight regardless of size; and furthermore this type is available in miniature sizes for airborne applications.

Capacitor Charge-and-discharge Type.—This is an old type, one European make having been brought out about 1904, but the devices were short-lived and not until 1944 did there appear (in the U. S.) an adequately durable polarity-reversing switch and associated mechanical components. Fig. 13 shows a typical circuit and arrangement of parts. Tachometer "heads" for continuous operation in fixed installations are said to be good for 2½ billion operating cycles (2½ billion shaft revolutions if no reducing gear-box is used).

8. MAGNETIC-DRAG TACHOMETERS

Most automobile speedometers are magnetic-drag tachometers. The principle of operation is that if a magnet is rotated near a metal disk, the disk tends to turn in the same direction because of eddy currents induced in the disk. A cross-section of a magnetic-drag tachometer is shown in Fig. 14. Rotating magnet C induces eddy currents in metal cup A, causing the cup to tend to rotate in the same direction as the magnet. The pull on the cup is proportional to the speed of the magnet. Restraining spring E opposes the rotation of the cup. Spring rate being linear, the cup's deflection is proportional to the speed of the magnet and the mph. scale (A) is linear.

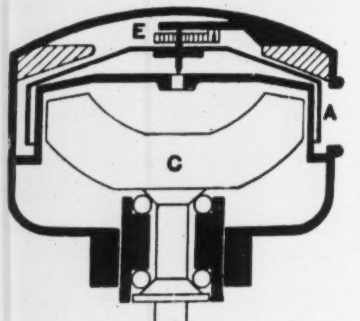

Fig. 14. Magnetic-drag tachometer.

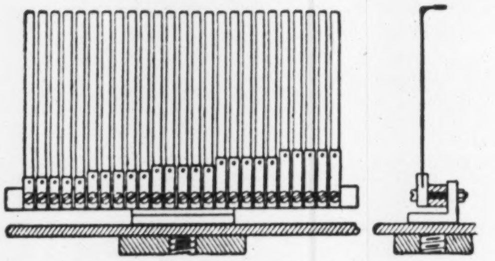

Fig. 15. Fig. 15. "Comb" of a vibrating-reed frequency meter, for rigid fastening to the housing of a machine whose speed is measured.

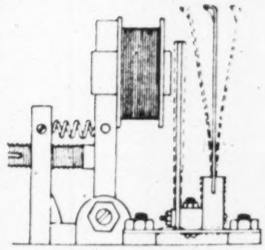

Fig. 16. Magnetic vibrator for exciting a "comb" at an electrical frequency.

9. FREQUENCY MEASUREMENT

Although frequency is synonymous with speed, it connotes the time rate of recurrent events rather than rate of motion. The vibration of machinery, the alternations of electrical phenomena, etc.. are expressed as frequencies and not as speed. This discussion deals only with electrical frequencies and industrial frequency-measurement instruments.

Vibrating reed.—The measuring unit consists of a row, or "comb," of thin nickel-plated spring-steel reeds, each about ⅛-inch wide, rigidly fastened at one end to a bar, or "bridge," and with their other ends bent at right angle and free to oscillate. Fig. 15 shows the reed "comb." As shown in Fig. 16 an electromagnet can be used to vibrate the comb at the frequency to be measured. The reed in resonance responds with the maximum vibration.

Electrical.—As commercially available, most electrical frequency meters have narrow ranges with "60.00" (or other standard) at scale-center. The resonant-circuit type and the bridge type are among the most sensitive of all electrical indicating instruments. The null-balance detector of a frequency bridge has long been used as the command element in automatic turbine-speed control systems. See Section 12.

Electronic—Electronic frequency-meters (for continuous waves) can be divided into two types—oscillators and adjustable resonant circuits. In oscillator types, the frequency of a built-in oscillator is compared with the unknown frequency to be measured. In resonant-circuit types, the resonant circuit is tuned until it is resonant at the frequency to be measured. As the circuit absorbs maximum energy at resonance, this type is called an absorption frequency meter.

Frequency measurement in industry is concerned more with the measurement of pulses than of continuous sinoidal waves. Pulses can be produced by pickups, such as shown in Fig. 2, and the indicator scales are calibrated more often in rpm. than in cps.

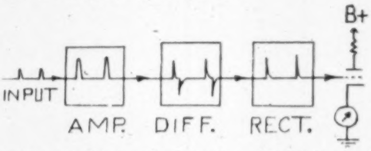
B+
INPUT
AMP.
DIFF.
RECT.

Fig. 17. Block diagram of a circuit for frequency measurement.

The block diagram of a typical instrument for measuring the repetition rate of pulses is shown in Fig. 17. The input pulses are amplified in a limiting amplifier, the output of which is similar to a square wave. The square-wave output is differentiated—that is, only the steep vertical portions are passed to the rectifier, which passes only the positive spikes. Thus the input to the measuring tube is a sharp, spiked, positive pulse for each input pulse. As the vacuum tube passes a small amount of current each time the positive spike reaches the grid, the average current through the tube is a function of the repetition rate of the input pulses. A d-c. milliammeter in the plate or cathode circuit measures the average current.

Electronic Frequency Meters.—These have already been mentioned under "Chronometric Tachometers." Fig. 18 shows two models, one (A) for ranges of interest in connection with machinery and processes. In this model the usual functions of signal and reference oscillators are reversed: what is directly counted is the number of microseconds during one cycle of the input whose frequency is to be measured. Fig. 18B is a conventional "frequency counter" for the 300-kc. to 3-Mc. range. Such instruments use the beat-frequency principle to count the number of

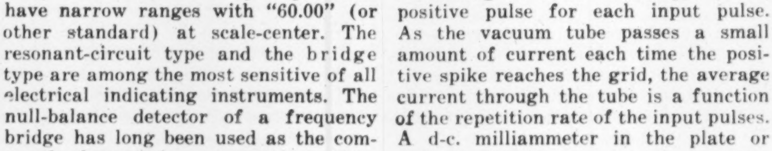
Crystal osc., 1 Mc.
Gate
Counter
Input
Pulse Former
Divider
Printed Readout
Ⓐ For "Very low" frequencies
meaning that in order to assure <1% error,
if frequency is <100 <10 <1 kc.
sampling period should be >.001 >.01 >1 sec.
because of irreducible error of ±1 count
"Level meter"
Amplif'r
Mixer
Low-pass filter <1.2 Mc.
Gate
Input
Harmonic Generator 2-41 Mc.
Counter
Crystal osc., 1 Mc.
Divider ÷ 2×10⁶
Printed Readout
Ⓑ For "High" frequencies with direct counting from 0 to 2 Mc.

Fig. 18. Block diagrams of electronic frequency meters.

pulses or the number of continuous-wave cycles during a sampling period (selected by a switch) controlled by a crystal oscillator. These electronic instruments are relatively expensive but, with commutating or scanning systems, they can rapidly monitor the speeds of a number of machines or processes from one console.

Highly accurate standards of frequency for radio-frequency and audio-frequency measurement are the standard frequencies broadcast from WWV, the station of the Central Radio Propagation Laboratory, National Bureau of Standards, Washington, D. C. This station broadcasts on frequencies of 2.5, 5.0, 10.0, 15.0, 20.0, 25.0, 30.0, and 35.0 Mc. Audio frequencies of 1, 440, and 600 cps. are modulated on the first six carrier frequencies at regular periods.

10. STROBOSCOPES

When a mechanism in rapid rotating, reciprocating, oscillating, or vibrating motion is glimpsed momentarily once each cycle at a given point in the cycle, it appears to stand still. This is because the impression made on the retina of the eye at each glimpse is retained during the brief interval until the next glimpse. A chalk mark on a revolving disk viewed once each revolution appears to stand still. It also appears to stand still if viewed every second, third, and so on, revolution. If viewed twice each revolution two stationary marks or spokes are visible. With a glimpse frequency of af cps. or af/b cps. (a and b being integers) the appearance is that of a stationary wheel of a spokes.

Similarly, a wheel having n spokes and viewed n times per revolution, appears to stand still. In the same manner as for one spoke, the apparent number of spokes is varied. Thus, if a wheel of n spokes rotates at f revolutions per second, and if the glimpse frequency is $f(na/b)$, it appears as a stationary wheel of na spokes. Deviation from this glimpse frequency causes the spokes to appear to rotate at a rate of $1/na$ cps., or one apparent spoke per second for each $1/b$-cps. deviation.

Speed and frequency can be measured by using the stroboscopic effect. In many cases a mark on a wheel is sufficient. The *stroboscopic disk* has made it possible to obtain wide readability with small variations in instrument speed.

There are three types of stroboscopes—interrupted line of sight, interrupted light, and intermittent light.

Interrupted line of sight.—This type of instrument consists essentially of a revolving disk or drum with slots in it. The disk is held in front of the eye and the moving object is observed through the slots. Thus the object is viewed intermittently at a frequency which depends on the speed of rotation of the disk, which is indicated by a small built-in tachometer.

Interrupted-light.—In interrupted-light stroboscopes, a source of continuous light, such as an incandescent lamp, illuminates the object viewed. However, the light path is interrupted by a revolving sector, or by a moving mirror. Thus the object is illuminated only for a short interval at the frequency of the interrupter.

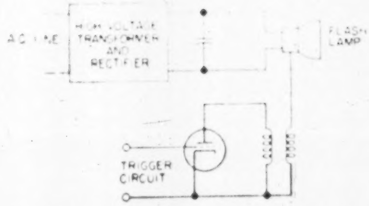

Fig. 19. Block diagram of discharge-type stroboscope.

Intermittent light.—In intermittent-light stroboscopes, the source of light is turned on and off at the frequency of viewing. Intermittent-light instruments usually employ gas-discharge type tubes, which can be ionized in microseconds. The duration of the flash from the instrument (which also is in microseconds) and the intensity, both depend on the size of capacitor discharged through the discharge tube. A typical intermittent-light stroboscope is shown in Fig. 19. The advantages of this type are the shortness of duration and high intensity of the flash. Portable instruments, known as "strobe lamps," are used with stroboscopic disks for checking the speeds of phonograph turntables and other constant-speed devices.

11. CHRONOGRAPHS AND OSCILLOGRAPHS

Chronograph.—A chronograph comprises a moving chart upon which a distinctive mark is made for each event. or revolution to be counted. The chart can be continuous strip, drum, or circular. Some charts have printed time-markings and are moved by a synchronous motor; others move at any speed and have time markings made by a pen or stylus operated by a tuning fork or controlled line-frequency. Most chronographs are used for measuring *velocity* (of projectiles, etc.) rather than speed.

Counter chronographs are numerical-display instruments, employing crystal oscillators as standard-frequency references. They indicate, by flashing a series of glow lamps or other digits, the time (in milliseconds or microseconds) between two events such as the passage of a projectile through two screens or coils separated by a known distance.

Oscillographs.—Electromagnetic or galvanometric oscillographs make recordings either by a light-weight pen or by a ray of light focused on moving film. The moving element, usually called the *galvanometer*, has a higher natural period of oscillation than that of an ordinary recorder. The inertia of the element is extremely small and there is little or no friction between recording element and the paper or film.

For extremely high-speed response, the measured magnitude deflects the electron beam in a *cathode-ray oscillograph* and the moving ray makes a record on a photographic plate.

The cathode-ray oscilloscope (not oscilloGRAPH) is used also in analyzing variations in the speed of equipment or mechanical vibration. The output of an electrical tachometer can be used as the input for the oscilloscope. Small shaft-speed variations can be shown on the screen.

12. ACCELEROMETERS

Methods.—Acceleration is the time rate of change of velocity. Velocity is the time rate of change of displacement. Therefore the three basic methods for measurement of acceleration involve the measurement of either (1) displacement and time, (2) speed and time, or (3) acceleration (direct measurement).

An example of method 1 consists in obtaining a record of the displacement of the object being studied. The slope of the recorded curve is the velocity of the object. These slopes can be plotted to give a curve of velocity. The slope of the velocity curve at every point is the acceleration of the object at that point. This method is that of absolute measurement and is employed in certain tests where the highest accuracy is desired.

A modification of the first method is found in recording forms of chronometric tachometers. The successive values automatically recorded are of *average* speed over the operation period of the instrument, generally one second. Therefore, this type is preferably used for studies of *slow changes* of acceleration where high accuracy is required.

The second method, measurement of speed and time, can be used with tachographs, which plot instantaneous speed against time. The accuracy to which such instruments actually record instantaneous speed depends on their kinetic behavior. The ordinary centrifugal tachograph either damps out transient fluctuations or overshoots when responding to a rapid change in speed. This is exactly what an accelerometer must NOT do. Only a few recording tachometers record transient variations in speed with sufficient fidelity.

The third method is to measure some effect of acceleration. The effect must be a function of acceleration, and of acceleration only. There are a number of such effects, but only a few are conveniently utilizable for purposes of measurement by direct-reading instruments that may be scaled in units of acceleration. These utilizable effects may be divided into three groups—(1) mechanical, (2) electromagnetic, and (3) electrostatic.

Electromagnetic methods use the transformer principles—that is, the voltage induced in the secondary of a transformer depends on the rate of change of the voltage in the primary. Electrostatic methods use the capacitor principle,—that is, the current flow through a capacitor depends on the rate of change of voltage across the capacitor. The main disadvantages of these methods is that the outputs depend not only on the rate of change of input but also on the amplitude of the input. Further, the former signal is

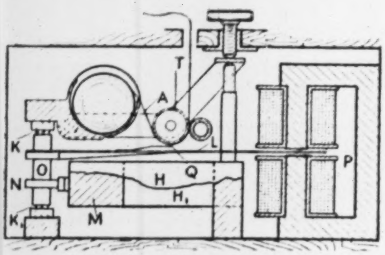

Fig. 20. Recording accelerometer.

much smaller than unwanted variations in the latter.

Therefore, mechanical methods, in which the force applied to a mass is directly equal to the acceleration, are utilized in the majority of accelerometers. The application of the principle consists in measuring the deflection of a mass suspended or pivoted with usually one degree of freedom and restrained by an elastic member, a damping resistance, or a gravity component. The instruments can be divided into (1) self-contained, and (2) systems comprising electrical-output pickups and remote recorders.

An example of the self-contained type is the recording accelerometer, Fig. 20, which can be used for recording either horizontal or vertical accelerations, depending on the position in which it is placed.

The mass M is supported by two flat steel strips, H and H_1, and is connected by means of an additional steel strip N to member O, which moves on knife edges K and K_1. This member carries a flat strip of aluminum L, one end of which is free to move between the poles of damping magnet P. Fixed to aluminum strip L is stylus Q. Any movement of the mass moves the stylus across record-tape A, which is driven by roller T by means of clockwork not shown in diagram. Magnet P is energized by a battery; thus damping is adjustable.

Rotation accelerometers.—These instruments record variations in the angular velocity of rotating bodies. They can be used for tracing and measuring cyclic fluctuations and other variations in the speed of internal-combustion engines and electrical machinery, as well as for measuring the comparatively steady angular accelerations in a motor starting from rest. The torsional resonances in any class of prime mover or driven machinery can be detected and their effects investigated.

Acceleration Pickups offer the advantage of small size and light weight, so that their use is not limited to vehicles or large machines. Units smaller than a sewing thimble are available.

Principal types of electrical-output acceleration pickups are: (1) resistance-wire; (2) piezoelectric; (3) electronic.

(1) *Variable-resistance* acceleration pickups (commonly known as "strain-gage" types) usually employ a mass-and-spring system with one degree of freedom. In many of the *bonded-wire* pickups, this mass is mounted on a deflection beam and strain-gage wires are bonded to both sides of the beam, so that when the beam deflects, the wires on one side are stretched and those on the other side are compressed lengthwise. In *unbonded-wire* pickups the mass is suspended by the wires themselves, all of which are in initial tension when the pickup is at rest. Thus, when the housing is accelerated and the mass moves with respect to the housing, no wires become completely slack. This type is capable of extreme sensitivity and high-fidelity response.

(2) *Piezoelectric* acceleration pickups can measure high accelerations without being damaged. (They facilitated development of the proximity fuzes for artillery shells.)

(3) *Electronic* acceleration pickups are modified radio tubes in which one electrode is movable and spring-supported.

All electrical-output acceleration pickups are more or less temperature-sensitive. Those for outdoor service (military, etc.) usually embody automatic temperature compensation; others should be used only at room temperatures. For more details on resistance-wire and piezoelectric elements see Sections 4(*d*) and 5 (*a*) of Part 3 of Chapter III on pressure measurement.

13. INDUSTRIAL SPEED CONTROL

Notes. (1) The customary term for an automatic speed controller is governor. The governor is an essential part of most prime movers other than engines and motors that drive vehicles, etc. (whose speed need not be constant).

(2) Study of the performance of prime-mover governors is the oldest branch of the science of automatic control. It provided the groundwork for modern process control engineering and servomechanism engineering.

(3) Owing to effects of inertance and momentum, an industrial speed-control application shares properties with both a process and a servomechanism. See Chapter XIII on Process Control and Chapter XIV on Servomechanisms.

(4) Industrial speed control differs from prime-mover speed control in that the user, as a rule, can select any one of a number of types (and makes) of speed control systems for a machine, an engine, a motor, a pumping station, etc.

(5) Some admirably sensitive and accurate types of speed measuring instruments cannot be adapted to speed control service conveniently (or at all). Others are excellently adaptable. Table I can be used as a guide. The types marked C and most of those marked RR can be incorporated into speed control systems.

One may define an industrial speed control instrument as the combination of any industrial speed (or frequency) measuring instrument with a controlled, standardized means (power cylinder, motorized valve, variable speed transmission, etc.) for increasing or decreasing the speed.

Flyball type.—Varieties of this principle constitute a major share of speed-control methods. Centrifugal flyballs can be used directly to position a valve, or they can position (1) a variable resistance, (2) a pilot in the control system, or (3) the pilot of a pneumatic transmission system to a standard pneumatic recorder-controller.

Four schematic diagrams (Figs. 21-24[*]) bring out the analogy between the evolution of an automatic speed control system and the evolution of industrial automatic controllers.

Fig. 21 shows schematically a self-contained speed controller in which the

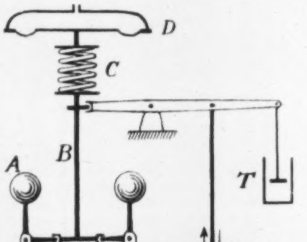

Fig. 21. Self-operating proportional-position governor.

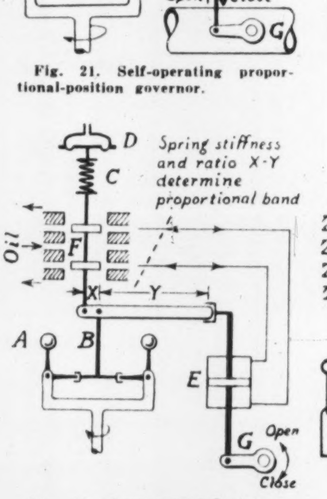

Fig. 22. Servo-operated proportional-position governor.

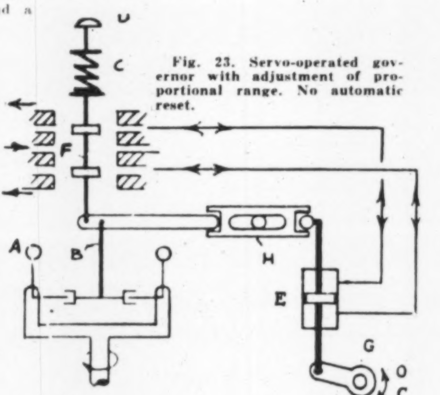

Fig. 23. Servo-operated governor with adjustment of proportional range. No automatic reset.

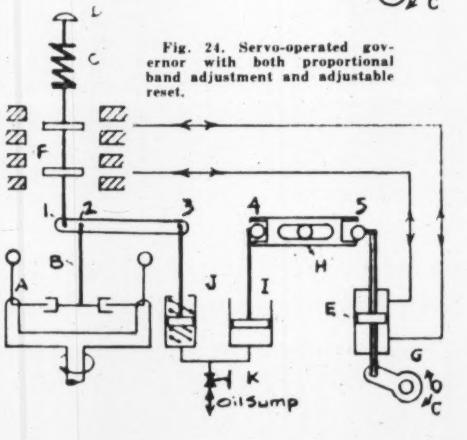

Fig. 24. Servo-operated governor with both proportional band adjustment and adjustable reset.

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[*] These diagrams and the accompanying presentation are based on a paper by J. G. Wilson, H. M. Karr and M. V. Long (Shell Development Co.), 1947 Instrumentation Short Course, Texas A & M College.

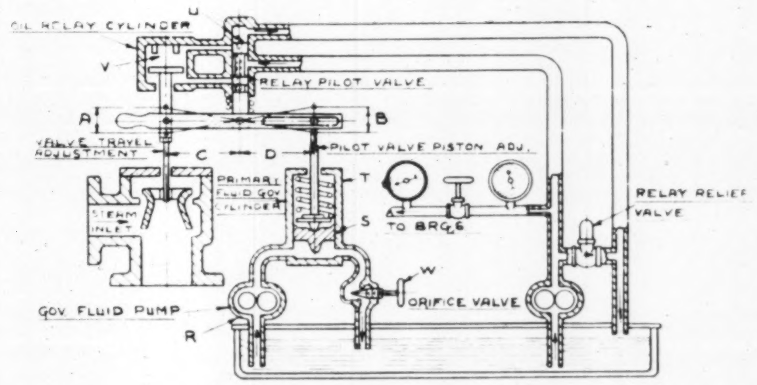
U
OIL RELAY CYLINDER
V
RELAY PILOT VALVE
A
B
VALVE TRAVEL ADJUSTMENT
C
D
PILOT VALVE PISTON ADJ.
PRIMARY FLUID GOV CYLINDER
T
STEAM INLET
S
TO BRG.6
RELAY RELIEF VALVE
W
ORIFICE VALVE
GOV FLUID PUMP
R

Fig. 25. Positive displacement pump governor.

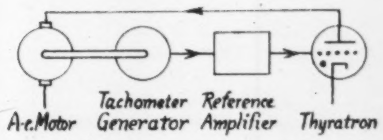
A-c.Motor
Tachometer Generator
Reference Amplifier
Thyratron

Fig. 26. Tachometer generator used in electronic speed-control circuit.

flyballs develop enough power to operate the throttle. On an increase in speed, flyballs A move outward, causing spindle B to move upward and valve G to move toward closed position. The speed control-point depends on the position of upper end of spring C, which is adjusted either manually by a screw (not shown) or by a remotely-controlled positioner such as air diaphragm D. As has been known for a hundred years or more, such a system is oscillatory; so dashpot T is provided to damp the cycling. But there will be a wide dead-zone on account of friction, especially at throttle G.

In Fig. 22, friction is overcome by hydraulic power, which is modulated by spool-type relay F and exerted by cylinder E. The hydraulic servomechanism is a follow-up, relay valve F being its error-detector and being returned to neutral after each change of position of the piston in cylinder E. The only friction to be overcome by speed-measuring element A is that of F. But this system, too, lacks adjustability of proportional band.

In Fig. 23 the fixed-ratio lever is replaced by one with an adjustable fulcrum (H) which permits the throttling range to be widened or narrowed. This, in turn, enables adjustment—but not elimination—of the "droop" or "offset" or "steady-state load error."

In the Fig. 24 system, the single lever is replaced by two levers (1-2-3 and 4-5), coupled by two hydraulic cylinders with a bleed between them. This arrangement provides automatic-reset or integral action, as in pneumatic process-control instruments.

Reset action: As point 4 moves downward, oil is transferred from cylinder I to cylinder J. This repositions point 1 to its neutral position. Excess pressure between the pistons is bled off to the sump (which has a positive head) so that the spring in piston J restores the piston to its normal position. As equilibrium is established, points 1 and 3 return to their original position, which means that the speed has been returned to its original setting.

Positive displacement liquid pump.—In this system (Fig. 25) a governor fluid pump and variable orifice replace the flyball unit and are used in the same manner as for a tachometer with a governor cylinder replacing the rpm. gage. Variable throttling range and automatic reset can be incorporated in this system as in the flyball system.

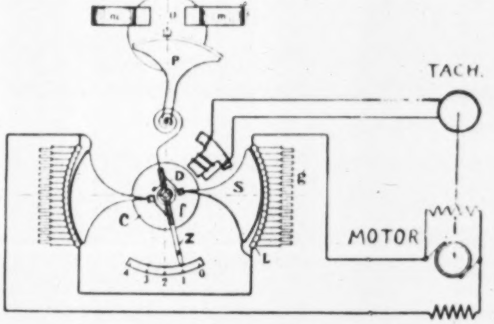
m
o
m
P
TACH.
D
S
E
C
Z
L
MOTOR
4
3
2
1
0

Fig. 27. Rocking-contact speed regulator.

D-c. tachometer.—The generator can be used in the following ways as part of a speed-control system:

(1) To generate current which operates a potentiometer-pneumatic controller.

(2) By installing contacts, usually high, normal, and low, to operate an electric motor positioner. This positioner can set speed contacts for an electric motor, set a throttle position, or operate any speed adjustment.

(3) Used as an integral part of an electronic circuit, as shown in Fig. 26.

(4) Used to supply varying voltage to an electric regulator for a motor.

Fig. 27 shows the wiring and essential parts of a "rocking-contact type" voltage regulator used for speed control. The voltage supplied by the tachometer generator positions drum C, which is counterbalanced by the torque of a spring. Rotation of drum C causes an increase or decrease of resistance in the motor-control circuit.

A-c. tachometer generator.—This generator can be used with contactors as in (1) above, or to supply voltage as in (4).

Null-type bridge circuit.—This circuit, most often used for frequency rather than speed, can be readily adapted to control as shown in Fig. 28. Although this mechanism has been superseded, we purposely show it because its *proportional-duration* control action differs from those of the previously-described controllers. For some speed control applications, this control action surpasses most others.

Unbalance in the frequency-sensing circuit deflects the galvanometer and the contactor ring. This causes one of the revolving cam contactors to come in contact with the contacts on the ring for a period varying in duration with the deviation of frequency from normal. This operates the synchronizing motor one way or the other, depending on whether the deviation is high or low. The synchronizing motor can operate a valve or a variable resistance in the motor-control circuit.

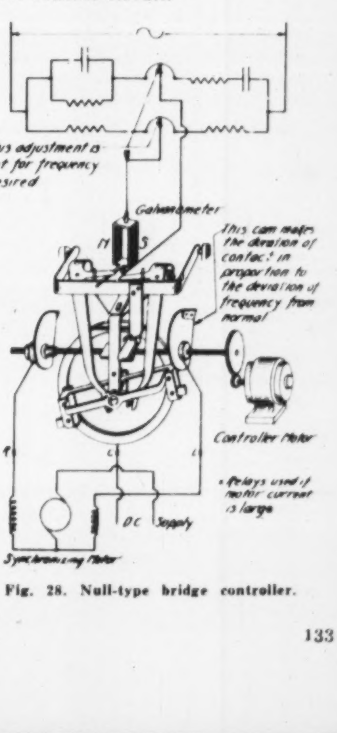
This adjustment is set for frequency desired
Galvanometer
N
S
This cam makes the duration of contact in proportion to the deviation of frequency from normal
Controller Motor
* Relays used if motor current is large
DC Supply
Synchronizing Motor

Fig. 28. Null-type bridge controller.

Fig. 29 shows a modern circuit in which the error signal caused by bridge unbalance is amplified and used to control the speed of a motor. Note the provision for rate and reset actions, both adjustable, as in pneumatic controllers.

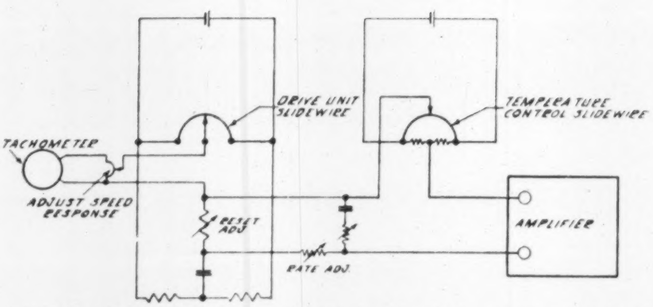

Fig. 29. Speed-control circuit with null-type frequency bridge as command element.

Variable-speed gears, transmission, etc.—This type of equipment includes many well designed and valuable commercial models. Few, if any, may be classified as speed controllers because, although a speed can be selected or changed remotely, no speed-sensing device compensates for changes in speed due to load, variations in prime-mover speed, or voltage variations on motor drives. These devices usually have a handwheel which can narrow or widen the faces between sheaves, change point of contact of gears, or otherwise vary relationships between the driving and driven members. This handwheel is replaced by a motor drive, an electric positioning drive, or even shafts and universal joints, to facilitate operation of the variable-speed drive from a remote location. An *automatic* speed controller involves going one step further by installing a tachometer generator in the positioning motor circuit. The handwheel, in another scheme, is replaced by an air motor actuated by a four-way diaphragm-motor valve. The motor valve is set by the output air of a standard pneumatic controller using one of the commercially-available pneumatic speed transmitters.

Electric motors.—The field of automatic speed control of electric motors has progressed to the point where a motor is obtainable for practically any industrial application. The following speed characteristics are obtainable.

(1) Rangeability as wide as 250:1.

(2) Stepless speed adjustment.

(3) Speed may be adjusted during operation.

(4) Calibrated speed settings.

(5) Control within 0.5 percent.

(6) Torque limit control.

(7) Variable acceleration and deceleration.

(8) Control of several machines to run at the same speed or at a given ratio to each other.

Conclusion.—A large percentage of the speeds measured today are measured using principles that were accepted as basic thirty years ago. Refinements have lengthened the life and increased the dependability and the accuracy of many of these systems.

Electronic methods for counting and speed measurements have facilitated the measuring of high speeds and rates.

The advent of reliable speed transmitters has made it possible to approach speed-control problems in the same manner and with the same equipment as is used in flow, temperature, or level measurement and control.

The pump governor has evolved from a throttle directly connected and actuated by a centrifugal-flyball element, to the pilot operators with all of the control refinements of a pneumatic controller. As applied to turbo-generators, these governors are expected to operate as precision instruments over wide load changes in exceedingly short time intervals.

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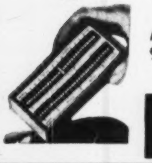

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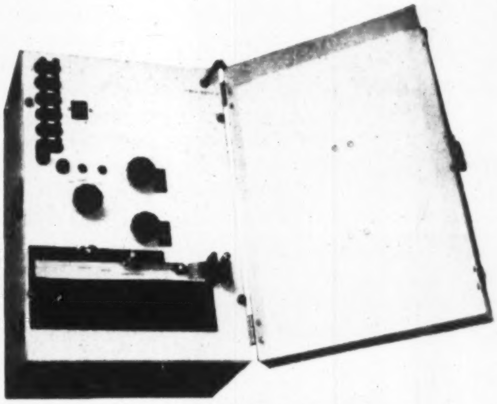

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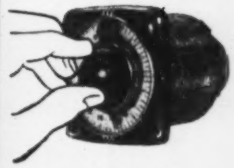

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S-60	1/5 sec.	60 min.	±.1 sec.
SM-60	1/100 min.	60 min.	±.002 min.
S-10	1/10 sec.	1000 sec.	±.02 sec.
S-6	1/1000 min.	10 min.	±.0002 min.
S-1	1/100 sec.	60 sec.	±.01 sec.
MST	1/1000 sec.	.360 sec.	±.001 sec.
MST-500	1/1000 sec.	30 sec.	±.002 sec.

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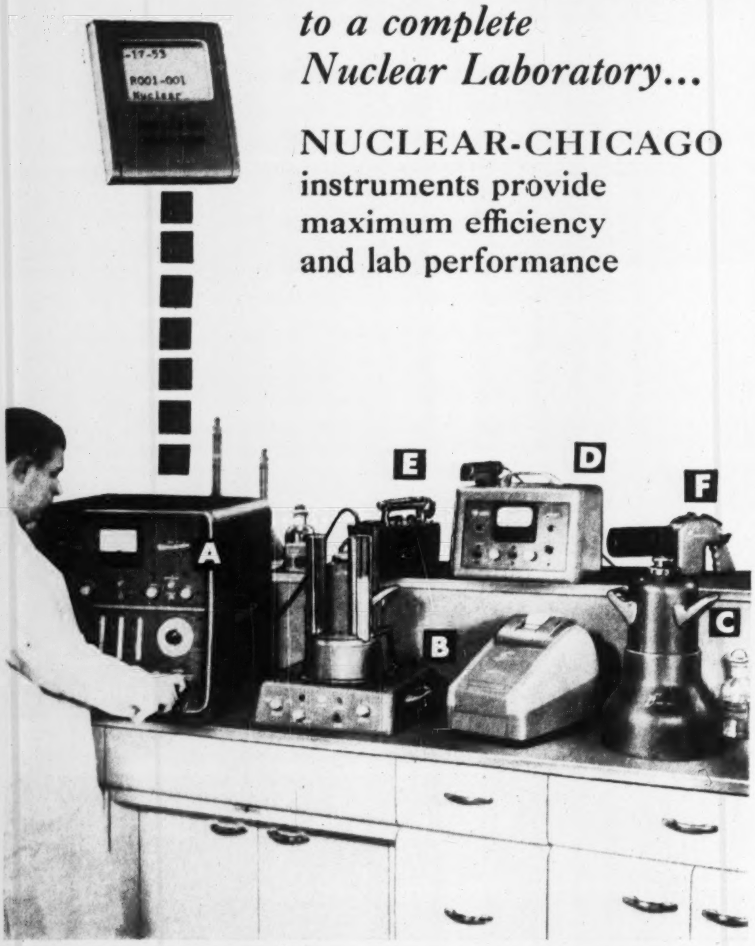

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CHAPTER IX

RADIOACTIVITY

By J. G. FOX and R. B. SUTTON

1. INTRODUCTION

THIS chapter deals with nuclear instrumentation in nuclear fields other than pure physics research. The following sections are devoted to the properties of the nuclear radiations and the means of measuring them, the most commonly used circuits, the uses of radioactive materials, "hot lab" instrumentation, and the techniques of health protection. Table I lists techniques which are used to measure properties of nuclear radiation. Table II lists the prime detectors and their properties.

Not described here are instruments which are primarily research tools; charged-particle accelerators; techniques of neutron diffraction; nuclear magnetic resonance; and the whole field of pile instrumentation.

2. PROPERTIES OF NUCLEI AND NUCLEAR RADIATION

The vast majority of nuclear instruments interact with the radiations which nuclei emit rather than with the nuclei themselves. Except for particles such as mesons, neutrinos, etc. whose interest is at present confined to nuclear research, these radiations are alpha particles, beta particles, gamma rays, neutrons, protons, deuterons, and (more rarely) heavier particles.

Our only means of ultimately detecting these radiations is by means of the ionization or excitation produced by a moving charged particle. This means that gamma rays and neutrons which carry no charge are not directly detectable and so we must make use of the charged particles which they may produce in the prime detectors listed in Table 2. In the case of gamma rays these are electrons (beta particles) and in the case of neutrons they are protons, alpha particles, fission fragments, and the beta and gamma rays emitted by nuclei which have absorbed a neutron and have been made radioactive.

Effects Utilized for Detection of Gamma Photons.—(1) A gamma photon may transfer all of its energy to an existing electron (photoelectric effect) or (2) part of its energy (Compton effect), or (3) if its energy is greater than about one million electron volts (1 Mev) may lose it, creating two electrons of opposite charge (pair production). Conversely (opposite of 3) a positive and negative electron may come together and disappear, producing annihilation radiation: two simultaneous gamma photons, each with about 0.5 Mev. energy and traveling in opposite directions.

Effects Utilized for Detection of Neutrons.—(1) Neutrons may transfer part of their energy to any nucleus in an elastic (billiard-ball-like) collision. The energy transferred and the ionization produced by the struck nucleus are greater the more nearly equal are the masses of the collision partners. (2) Neutrons are absorbed readily by boron and lithium nuclei with the resulting emission of energetic alpha particles. The probability of absorption is inversely proportional to the velocity of the neutron for slow neutrons. The dividing line between slow and fast neutrons is not sharp but is about a few electron volts. (3) Neutrons absorbed by some of the heaviest nuclei can cause them to split into two heavy fragments (fission) which produce a very great deal of ionization. (4) Finally, when many nuclei absorb neutrons, they become radioactive, emitting beta or gamma rays.

It is assumed that the energies of all particles except fission fragments discussed in this chapter are less than about 10 or 20 Mev. For these energies alpha particles, protons and deuterons have a density of ionization along their paths of the order of 100 times greater than that for beta particles. This makes it possible for certain detectors to distinguish electrons from the heavy particles.

Charged particles of a definite initial energy will travel only a certain distance (range) through a given material. Gamma rays and neutrons do not have a definite range: the intensity of gamma rays decreases exponentially with distance and that of neutrons in a more complicated way.

QUICK REFERENCE DATA ON RADIATIONS EMITTED BY NUCLEI

For complete details see Table I

Gamma Rays are electromagnetic waves of extremely short wavelength—from about 0.001 micron* to about 0.1 micron. They are much more penetrating than x-rays.

Beta Particles are free electrons and free positrons. Each electron carries one unit negative charge; each positron carries one unit positive charge.

Alpha Particles are the same as the nuclei of helium atoms. Each alpha particle carries two unit positive charges. It consists of two protons and two neutrons, so that its mass number is four.

Protons are the nuclei of hydrogen atoms. Each proton carries one unit positive charge. Its mass number is one.

Deuterons are the nuclei of deuterium ("heavy hydrogen") atoms. Each deuteron carries one unit positive charge but its mass number is two.

Neutrons are constituents of all atomic nuclei except hydrogen. A neutron carries no charge. Its mass number is one.

---

*The micron is a unit of length equal to one-millionth of a meter (one thousandth of a millimeter).

Radioactive nuclei occur naturally and are also produced by bombarding stable nuclei with energetic charged particles, gamma rays and neutrons. The large number of neutrons produced in controlled fission chain reactions (piles) makes these a copious source of radioactive elements. The time required for the intensity of radiation emitted by a radioactive element to decrease by one half is known as its half life. Known half-lives range all the way from 10^{13} years down to 10^{-9} second and serve to identify radioactive elements. As a rough general rule, the shorter the half-life the more intense the radioactivity which can be obtained in practice.

Other types of nuclear radiation (such as mesons) are produced by cosmic radiation and the high-energy particle accelerators. They will not be discussed here because they are not being "used" at the time of writing.

3. CIRCUITS

1. *Scaling Circuit.*

The function of this circuit is twofold: first it reduces the number of pulses per second provided by the primary detector by a known ratio to a rate which the mechanical counter, which finally records them, can follow; second it spreads its output pulses more uniformly in time and so decreases the fraction of pulses which happen to occur in closely-spaced pairs and hence are missed by the mechanical counter.

The basic unit of most scaling circuits is the scale-of-two element whose output pulse rate is half the input rate. If N of these elements are connected in series, the ratio of output to input pulses is $1/2^N$ (binary scaler). The circuit may be modified to make the ratio $1/10^N$ (decade scaler). A satisfactory scale-of-two unit which is used in the Higinbotham circuit is shown in Fig. 1. The terminal marked "out" of one unit is connected to the terminal marked "in" of the next.

Basically, the scale-of-two unit is a multivibrator flip-flop which is stable when either T_1 or T_2 is conducting and the other not. When T_2 of the preceding stage becomes conducting, a negative step signal is applied to the

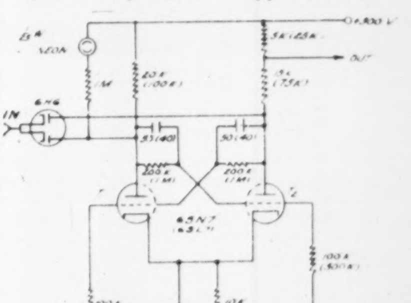

FIGURE 1
BASIC SCALE-OF-TWO CIRCUIT

TABLE I—PROPERTIES AND INSTRUMENTATION OF NUCLEAR RADIATIONS

	Beta Particles		*Gamma Rays*	*Neutrons*		*Alpha Particles*	*Other Heavy Particles*
	Negative	*Positive*		*Slow*	*Fast*		
Charge	-4.802×10^{-10} **e.s.u.**	$+4.802 \times 10^{-10}$ e.s.u.	Zero	*Zero*		$+9.605 \times 10^{-10}$ e.s.u.	**$+4.802 \times 10^{-10}$ e.s.u. for protons and deuterons.**
Rest Mass	9.107×10^{-28} gm.		Zero	1.675×10^{-24} gm.		6.644×10^{-24} gm.	1.672×10^{-24} gm.—proton 3.342×10^{-24} gm.—deuteron
Range	For beta particles from radioactive substances: $R = 0.542 \times E^{-0.133}$ for E greater than 0.8 $R = 0.407 \times E^{1.38}$ for **E between 0.15 and 0.8** } { R in gm/cm^2 E in **Mev.**		No range; absorption is exponential. Intensity of 0.5 Mev. gammas is reduced to half by about 0.4 **cm. of lead.** Intensity of 1.0 Mev. **gammas** is reduced to half by **about 1** cm. of lead.	No range; absorption is expotential; **absorption** coefficient varies enormously **and irregularly with** element and energy. Intensity of 0.3 ev. neutrons reduced to **half by** 4 cm. of lead or 0.005 cm. of **cadmium.**	Intensity of 1-10 **Mev.** neutrons reduced to half by 3 or 4 cm. of lead.	7.3 cm. of air at N. T. P. for energy of 8 Mev. 4.5 cm. of **air** at N.T.P. for energy of 6 Mev. 2.5 cm. **of air at** N.T.P. for energy of **4 Mev.** (Note 5)	**46 cm. of air at N.T.P. for energy of 6 Mev.** **23 cm. of air at N.T.P. for energy of 4 Mev.** } for protons.
Source	Natural radioactivity. **Induced radioactivity.**	Nuclear accelerators, e.g. betatron Secondary **effects** of **gamma rays**	Natural radioactivity. Induced radioactivity. **Secondary effects of beta particles.**	Fast neutrons **slowed** down by **a moderator.**	Nuclear reactions, especially controlled fission chain reactions in piles.	Natural radioactivity. **Transuranic elements produced by nuclear reactions. Nuclear accelerators e.g. cyclotron, van de Graaff** generator.	**Nuclear accelerators, e.g.** cyclotron, **van de Graaff** generator.
Means of Detection	Any primary detector, usually 1, 2, 4, 5, 7.*	Annihilation gamma rays.	Secondary beta particles produced in primary **detectors.**	Induced radioactivity. Disintegration of boron or lithium in **detectors 2** or 3.* Fission in **detector** 2.	Collision with light nuclei e.g. hydrogen or helium in **detectors** 2 or 3.* **Disintegration of** boron or lithium in detectors 2 or 3. Fission in detector 2.	**Usually with detector which can** discriminate, especially 2, 3, 5.* Possible with any prime detector.	**Same as for alpha particles.**
Measurement of Energy	**Absorption in aluminum; this gives approximate upper limit of energy of beta rays from radioactive substances; accuracy about 10 percent. Deflection** in electric or magnetic fields; accuracy **about** 1 percent.		Less than 1 Mev.—**Diffraction** by crystal **grating**—accuracy 0.1 percent and better at lower energies. Less than 5 Mev.—**Energy of** secondary photoelectrons or Compton electrons—accuracy 1-2 percent. **Absorption** in lead—accuracy 5-10 percent. More than 5 Mev.—**Energy** of coincident **positive** and **negative electron pairs measured** by **deflection** in magnetic **field.**	Crystal diffraction. Mechanical velocity selector. Time of flight measured electronically } accuracy about 1 percent or **better at low energy**	**Energy** of recoiling light nuclei in **collisions; measured with detectors** 2 or 3* **and associated circuits; accuracy 1 percent or better. Fast** neutron-induced **radioactivity or nuclear reactions** (e.g. **fission**) may permit **a lower** limit to be set.	Absorption in aluminum or **air;** accuracy **about** 1 percent. **Deflection in magnetic** field; accuracy 0.1 percent or better. **Discrimination of pulse size in detectors** 2, 3, 5 **with associated circuits; this method limited in** practice **to energies of a** few Mev or **less; accuracy** about 1 percent.	**Same as for alpha particles.**
Measurement of Intensity	**Deflection of detector 1.* Instruments to measure current or charge collected** in detector 2. **Scaling, integrating, and counting** rate **circuits with detectors 4, 5, and sometimes 3. Blackening of detector 7.**	Intensity of coincident 0.5 Mev. annihilation gamma rays.	Same as for **betas.**	Detectors 2 or 3* containing boron or lithium with associated circuits. Detector 2 containing fissionable material. Amount of induced radioactivity.	Detector 7* examined under a microscope. Recoils of light nuclei such as hydrogen or helium in detectors 2 or 3; associated circuits. Detectors 2 or 3 containing boron or lithium and surrounded by paraffin for increased efficiency; associated circuits.	Deflection of detector 1.* Detector 2 **with associated circuits to measure either current** (high intensity radiation) or individual pulses (low intensity radiation). Detectors 3, 5 with associated circuits to measure pulses. Detector 7 examined under a microscope. When detectors 1, 2, 3 are used they must have no window or else an extremely thin window.	**Same as for alpha particles.**
Elimination of Background	Eliminate gammas and neutrons by measuring with and without beta absorber. Eliminate alpha particles by measuring with alpha absorber.		Eliminate alphas and betas by measuring with appropriate absorbers. Eliminate neutrons by using detectors insensitive to neutrons.	Eliminate alphas and betas with absorbers. Eliminate gammas by bucking currents from two ionization chambers which have equal sensitivity for gammas but different for neutrons (note 3). Reduce relative intensity of gammas to neutrons by using as absorber a few cm. of a heavy metal e.g. lead or bismuth (note 4).		Eliminate beta and gamma rays by using detectors which can discriminate e.g. 2, 3, 5; also 7* with microscope examination. **Eliminate fast neutrons by measuring intensity with and without a thin alpha absorber. Eliminate slow neutrons by 1 mm. cadmium absorber.**	**Same as for alpha particles.**

Monitoring Instruments (Note 7)	**Personnel Integrated Dose**	Blackening of detector 7* in badge worn on clothing; sensitivity is 30-30,000 millirem. (see note 1)	Detectors 7* as for betas. Part of film covered with metal to eliminate betas. Detectors 1 and 2 carried in pocket; sensitivity 0-200 millirem (note 1). Instruments obtainable which give audible signal when dose reaches certain amount. Detector 2 to measure integrated dose near worker. Sensitivity 0-200 millirem.	Detectors 1 or 2 lined with boron; sensitivity 0-200 millirem. (Note 1) Detector 7 containing nitrogen examined with microscope. Blackening of detector 7 with crossed strips of cadmium and lead. } under development; can detect subtolerance dose.	Detector 7* with cadmium shield to eliminate slow neutrons; recoil tracks examined under microscope; under development; can detect subtolerance dose.	—	—
	Personnel Contamination	Detector 4* with 30 mg/cm² wall. Single or multiple instruments available which can monitor both sides of hands and shoe soles simultaneously. Also instruments which measure inside shoes, cuffs etc. Also instruments to measure radioactivity collected in nose.	Same as for betas.	—		Detectors 2, 3* with large nylon window; can scan surfaces of hands or clothing; some portable, some not; instruments using detector 3 give instantaneous readings, with detector 2 there is 10 second lag; sensitivity up to 5,000,000 d.p.m. (Note 6).	—
	Laboratory Survey	Detectors 1, 2, and 4.* Many models available. Those using detectors 1 and 2 best for quantitative measurement.	Same as for betas.	—		Detector 2* with large nylon window as above.	—
	Air	Electrostatic precipitation of dust or use of filter paper. Count with detectors 2 and 4 (mica end window) respectively. Continuous operation air flow instrument moves filter paper past detector 5 or 4 (30 mg/cm²)—under development. Radioactive gases in air monitored by putting them inside detector 3 (under development) or in a pig (Note 2) containing detector 4 (30 mg/cm² wall). General background measured with detector 2 or 4 (30 mg/cm² wall). Those using detector 2 and vibrating reed electrometer very sensitive and quantitative.	Same as for betas.	—		Electrostatic precipitation of dust which is then counted with detector 3.* Continuous operation air-flow instrument moves filter paper past detector 5—under development.	—
	Water and Sewage	**Same as for alpha particles but using detector 4* with mica end window counter.** Water flows around detector 4 or through jacket around detector 4—not as sensitive as evaporation method.	Same as for betas.	—		Dry residue after evaporation of water or filtering of sewage is counted with detector 2 or 3.*	—

NOTES

*Detectors are numbered as in Table II.

(1) **See** Section 6 for definition of rem.

(2) Pig—A shield of about one inch of lead, completely enclosing a volume large enough to contain detector and radioactive sample.

(3) Since absorption of gamma rays by matter varies smoothly with atomic number while absorption of neutrons varies irregularly (e.g. boron and lithium absorb much more strongly than helium, beryllium, and carbon) this is readily arranged.

(4 Compare under "Range" above the thickness required to reduce intensity of gammas and neutrons to half.

(5) For all elements with approximately the same atomic number as air the range for a given energy is inversely proportional to the density.

(6) d.p.m.—Disintegrations per minute.

(7) A more detailed description of commercially available monitoring instruments may be found in "Radiation Instrument Catalog" compiled by the Radiation Instrument Branch; obtainable from Technical Information Branch, AEC, Oak Ridge, Tennessee. Price 95 cents.

plate of the "off" tube and through the *RC* network to the grid of the adjacent "on" tube. This causes the flip-flop to pass to its other stable state. When T_2 of the preceding stage becomes nonconducting, the resulting positive step signal does not change the state of the flip-flop.

The element shown in the diagram has a resolving time of 3 to 5 microseconds. If the circuit constants shown in parentheses are used the element will use less power and have a resolving time of about 20 microseconds.

2. *Coincidence Circuits.*

These are used to couple the pulse output from two or more counters and so indicate simultaneous arrival of particles at the counters. Such circuits are useful in determining such things as the direction of a particle (particles counted if they go through counters in line), reducing background (particle to be counted has to go through two counters, while random counts in either not recorded) and many other applications. The circuit is usually one with an output which is non-linear with respect to the input, e.g., two similar simultaneous pulses in give an output much higher than twice that for one pulse in. Examples are: multigrid tubes, such as mixers, with two grids biased off so that both must go positive to get an output signal; a parallel arrangement of triodes in what is known as a Rossi Circuit shown in Fig. 2. Here both tubes are normally conducting. If a negative pulse comes into one grid and cuts off one tube, the current through *R* decreases somewhat so that a small voltage pulse appears at the output. If both tubes are cut off, a large change in current occurs, and the voltage drop across *R* disappears.

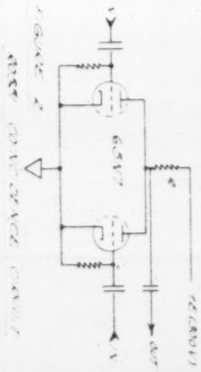

FIGURE 2

ROSSI COINCIDENCE CIRCUIT

3. *Discriminator Circuits.*

Usually it is desirable to count only those pulses from a pulse amplifier or Geiger-counter tube above a certain minimum value. In the case of ionization chambers, proportional counters and scintillation counters, where the pulse height depends on the energy and type of particle, use of a circuit to discriminate against those pulses below a certain value will allow determination of such things as number of particles as a function of energy, flux of one type of particle in the presence of other particles, and will make it possible to avoid counting noise pulses or pulses from the sparking or fluctuation in the voltage supply. In the case of Geiger counters such circuits serve the purpose of eliminating pulses from the voltage supply and also provide a high impedance for the counter to feed into and an output to drive a scaling circuit. Such discriminator circuits are generally some type of trigger circuit which, if it operates at all, puts out a pulse of fixed size independent of the input pulse. Thyratron tubes were used extensively in the past but lately hard-tube circuits have been used since the counting rate can be faster.

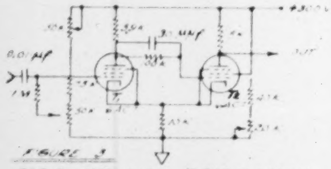

FIGURE 3
BASIC AMPLITUDE DISCRIMINATOR

Such a circuit is shown in Fig 3. When its grid voltage is zero, T-1 is cut off and its plate is close to the +300 volt supply potential. The grid of T-2 is at about +100 volts and hence draws current until its cathode potential rises to +104 volts. This is also the cathode potential of T-1 and is the reason T-1 is cut off. As the input voltage rises, nothing happens until the grid of T-1 reaches the neighborhood of +100 volts and T-1 begins to conduct. This increases the current through the common cathode resistor, causing T-2 to conduct less and at the same time decreases the plate voltage of T-1 which is fed to the grid of T-2, causing it to conduct still less. The net result is a sudden transfer of current from T-2 to T-1. This new situation prevails as long as the grid voltage of T-1 is greater than about 100 volts. When it drops below this value, the reverse change occurs. Thus an output pulse is obtained of fixed amount which lasts as long as the grid of T-1 remains above a fixed value (in this case +100 volts). The size of input pulse which will trigger this circuit may be varied by changing the normal grid bias of T-1 and T-2.

4. *Counting Rate Meter.*

This is a device by which counting rates are indicated by an ordinary pivoted-coil indicating instrument. It is suited for monitoring instruments and can be used to obtain a continuous record of the intensity of radiation. It is less accurate than a counting circuit.

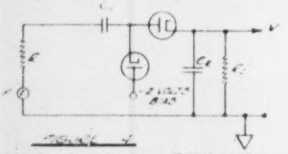

FIGURE 4
BASIC COUNTING-RATE CIRCUIT

The circuit is so arranged that each pulse to be counted causes a definite amount of charge to be placed on a capacitor whose charge then leaks off through a high resistor, making the average capacitor voltage proportional to the counting rate. It is necessary that each input pulse have the same height, E, and a duration short compared to the average spacing between pulses. The basic circuit is shown in Fig. 4. Each pulse produced at P deposits an amount of charge $q = C_1E$ on C_2. The average potential V is then $V = IR_2 = nqR_2 = nC_1ER_2$. Pulses of either sign can be used. The two-volt bias prevents undesired current flow through the diodes from such causes as contact potential differences.

5. *Voltage Supplies.*

(*a*) *For Geiger-Mueller Counters.*—A supply with a range of output voltage from about 500 to 2,000 volts d.c. is required to operate most available Geiger tubes. The output should be continuously variable, and stabilized to about 0.1 percent output voltage change per percent change in line voltage. An output current of a few microamperes is sufficient. Apart from the battery supply, the simplest is probably the 60-cps. half-wave rectifier stabilized by a voltage regulator such as the 900-volt gas regulator now available, with a voltage divider across the output. For higher voltage than 900, two such tubes may be used in series.

(*b*) *For Proportional Counters.*—A supply with a voltage range up to 2,500 volts d.c. is required. Since usually a proportional counter is used in order to be able to select particles by pulse size, good stability is required if the pulse size and hence particle type selected is to remain constant. Hence there is a greater tendency to use batteries here than for the Geiger counter. A few microamperes of current is sufficient.

(*c*) *For Ionization Chambers.*—The voltage required depends on the characteristics of the chamber. It should be high enough to reach the saturation value of charge collected, i.e., so that little or no recombination of ions occurs. If this is obtained, changes in voltage will not change pulse size (or current) provided that when pulses are being recorded the characteristic time for discharge of the chamber capacitance is long compared to the collection time of the ions. In any case, ripple and sparking must be kept low since the pulse or charge is small compared to the case in (a) and (b). Batteries may be the most useful type of supply. The ionization current is the only drain.

(*d*) *For Electron Multipliers.*—A well-stabilized supply of about 1,000 volts d.c. is required. It is distributed to the plates from a voltage divider. The size of this divider—which will determine the current required—should be chosen so that at the current through the tube the voltage on the plates is essentially the same as for zero current. Batteries are commonly used.

6. *Amplifiers.*

(*a*) *For Proportional Counters.*—A voltage gain of about 10^4 is required, but this figure depends very much on the multiplication obtained in the counter; an output of about 40 volts should be achieved. The amplifier must be linear, i.e. output proportional to input. The input capacitance should be low and the input noise low. The initial rate of rise of the pulses is quite rapid, so that a "fast" or wide-band amplifier may be used with a short recovery time in order to make the pulse duration short. An amplifier with a response time of a few tenths of a microsecond and a decay time slightly longer will give pulses lasting about a microsecond. So short a decay time will clip off part of the pulse. Resistance-capacitance coupled amplifiers are generally used, the important characteristics being low plate resistors, low plate and grid capacity and high g_M tubes (such as 6AK5 or 6AC7). A short characteristic time (coupling capacitor and grid resistor) is used in one stage to provide the short recovery time.

(*b*) *For Ionization Chambers.*—Amplifiers similar to those for proportional counters are used except that the gain usually must be higher: 10^5 or so. With amplifiers of this type, only the motion of the electrons in the chamber will be detected, so that the pulse height will depend on where in the chamber the ions are formed as well as on the number of ions. If slower amplifiers are used, i.e. with longer decay times (about 100 microseconds) the motion of the positive ions will also contribute to the pulse and the pulse height will be independent of position. Using amplifiers with lower frequency response is necessary if the gas in the counter is electronegative and captures the electron. If the high-frequency response is lowered, as it then may be, the signal-to-noise ratio is improved. Low noise is an even more important consideration in the case of ionization-chamber amplifiers than in that of proportional-counter amplifiers, since no gas multiplication occurs.

(*c*) *For Scintillation Counters.*—Since pulses from the multiplier are quite large—a few tenths of a volt—the amplifier gain needs to be only several hundred. However the pulse rise time is very short, of the order of 10^{-8} sec. so that extremely fast amplifiers should be used to take full advantage of this type of counter in certain applications such as measuring source-decay times or coincidence counting. Perhaps the best type of amplifier to use is the distributed-constant type. This type of amplifier responds to frequencies up to 100 or 200 Mc. or has a rise time of 10^{-8} sec. or less. However, the amplifier gain is only the gain per stage times the number of stages and so is rather low.

(*d*) *D-c. Amplifiers.*—

In cases where the average current due to ionization in an ionization chamber, or the average current in a multiplier, is to be measured, direct-current amplifiers are often used. Such amplifiers are generally one-tube amplifiers, the tube used being a special electrometer tetrode or pentode. These tubes have as characteristics an extremely low grid current (about 10^{-13} to 10^{-17} amp.) and thus permit the

TABLE II—PRIME DETECTORS (See Note 1)

Properties \ Type	*1 Electroscope*	*2 Ionization Chamber*	*3 Proportional Counter*	*4 Geiger-Mueller Counter*	*5 Scintillation Counter*	*6 Cloud Chamber*	*7 Photographic Emulsion*
Basis of operation (See Note 2)	Measures total charge accumulated on electrodes.	Measures total current constituted by motion of primary ions produced directly by particle detected.	Primary ionization multiplied in electric field by fixed amount.	Primary ionization multiplied in high electric field into an avalanche whose size is independent of primary ionization.	Photo-multiplier tube detects light from fluorescence produced by ionizing particle moving through phosphor.	**Droplets of vapor form on ions produced by ionizing particle.**	**Grains made developable by passage of charged particle.**
Counts individual particles?	No.	Yes.	Yes.	Yes.	Yes.	Yes.	Yes.
Differentiates between particles?	No.	Yes.	Yes.	No.	Yes, to some extent.	Yes.	Yes.
Duration of one event		Depends on gas and voltage; as low as 0.1 microsecond.	Several microseconds.	100-200 microseconds	Depends on phosphor used; as low as 0.001 microsecond.		—
Associated circuits (See Note 3)		For observing individual pulses: 1, 2, 3, 4, 5(c), 6(b). For measuring flux: 4, 6(d). (See Note 3)	1, 2, 3, 4 (for flux), 5(b), 6(a). (See Note 3)	1, 2, 3, 4 (for flux), 5(a). See Note 3)	1, 2, 3, 4 (for flux) 5(d). (See Note 3).		—
Used for half-life determinations?	Yes.	Yes.	Yes.	Yes.	Yes.	No.	No.
Pulse size		Depends on ionization and hence energy and type of particle. Ranges up to tenths of a millivolt	Proportional to ionization of particle. Ranges up to millivolts.	Independent of particle type or energy—the order of volts.	Depends on energy of incident particle; different particles of same energy may not give same pulse size. Ranges up to tenths of a volt usually but may be higher.		
Directional?	No.	Yes.	Yes.	Only if central wire is beaded.	Yes.	Yes.	Yes.
Remarks	Many types available; some portable.	Various fillings are used to give more or less sensitivity to certain particles. For rapid collection of charge electronegative gases are avoided.	Various fillings give more or less sensitivity to certain particles. Multiplication depends on voltage, gas pressure and geometry.	Various types are: self-quenching, non self-quenching, thin wall, thin end wall, flow counter, (no absorbing wall), limited life (organic vapor in filling), unlimited life (halogen gas filling), etc.	Characteristics determined mainly by phosphor used; organic (anthracene, napthalene) decay rapidly, inorganic (zinc sulphide) decay slowly but give more fluorescent light. (See Note 4)	Observes complete nuclear events. Characteristics of vapor tracks used to determine energy, direction, and type of particle. Used mainly for research. Rather complicated construction.	Can be used to examine tracks of individual particles and complete nuclear events, or to measure integrated intensity from amount of blackening. Good microscope required to observe individual tracks and events.

NOTES

(1) In addition to the seven types of prime detectors listed at the tops of the columns, there are Crystal Detectors and Electron Multipliers, but these two types are used very little and only in research.

There is also the Radioelectric Cell (Ohmart Cell or "atomic battery") which utilizes the radioelectric effect (direct conversion of radioactive energy into a continuous electric current). It is used for measuring industrial process variables such as liquid levels, rather than for measuring and analyzing radioactivity which is the specific subject of this table.

(2) Electroscopes, ionization chambers, proportional counters, and Geiger counters are basically the same instrument. They all contain a gas and two electrodes at different potentials which collect the charged ions produced in the gas. In an electroscope the force between the insulated electrodes causes one of them to deflect as the potential difference is changed by the collected charge. In an ionization chamber the electric field is low enough so that there is again no multiplication as the primary ions are accelerated and only the primary ionization is measured. In a proportional counter the electric field is raised to the point where the primary ions are accelerated sufficiently to produce other ions. This multiplication can be made as great as a thousand-fold or more and can be kept constant. In a Geiger counter the electric field is still greater and the multiplication becomes so great that the flow of ions becomes a gas discharge whose intensity is independent of the amount of ionization which triggered it. This however is rapidly stopped in self-quenching counters by the special properties of the gas filling and in non-self-quenching counters by the external electric circuit.

(3) Numbers refer to those in Section 3 of text.

(4) With scintillation counters the light emitted by the recombining ions can be "piped" some distance through transparent plastic of various shapes to the phototube which permits various interesting applications.

measuring of currents which are of this value. The voltage amplification is generally less than unity, but the current amplification can be of the order of 10^5. The simplest circuit consists of a grid resistor of 10^{10} to 10^{12} ohm, a sensitive current meter (galvanometer if necessary) in the plate circuit, about 6 volts plate voltage, 15 volts screen voltage, and -3 volts grid voltage. The difficulties encountered with such circuits generally appear in the form of the plate-current drift caused by changes in emission current. Using a bridge type circuit, (for example one such tube in each of two arms of a bridge, and using the same filament supply for both) can eliminate some of this trouble.

A second type of d-c. amplifier converts the d-c. signal, developed across a resistor in series with the chamber, into an a-c. signal, by means of a mechanical vibrator (vibrating reed or vibrating capacitor) and amplifies the a-c. signal by using an a-c. amplifier. The advantage here is obviously that if the amplifier is linear changes in bias will not affect the output signal and hence stabilization is easier. Currents as low as 10^{-17} amp. can be measured.

4. USE OF RADIOACTIVE MATERIALS

These materials are useful for two main reasons. First, application can be made of the radiation emitted; secondly, the property of being radioactive makes it possible to determine the location of the material (qualitatively and quantitatively) in tracer techniques.

1. *Use of Radioactive Sources*

(a) Measuring the level of liquids or granular materials in tanks, bins, standpipes, etc. One method involves the use of a vertical strip form of radioactive source on one side and a vertical stack of radiation detectors on the other.

(b) Continuously measuring the thickness of moving sheets, etc., being processed. One method involves the use of a radioactive source, a measuring detector and a second detector to compensate for background radiation and for decay of radioactive source.

(c) Continuously measuring the density of liquids flowing in pipelines. One method uses a compensating detector as in (b) but here the compensation is chiefly for the pipe-walls, in order to have a zero reading when the pipe contains no liquid.

(d) Measurement of liquid-liquid interface in pipe lines. Here the compensating-detector current and the amplifier sensitivity are so adjusted that the scale of the indicator or recorder reads

"0 to 100" for a narrow range of specific gravities, for example 0.50 to 0.70.

(e) Measurements of thickness, specific gravity, etc., by measuring the back-scattering. In these applications the gamma-ray source and the detector (separated from each other by a lead shield) are on one side of the measured material, so that the detector measures the intensity of those rays which are reflected in its direction.

(f) Treatment of cancer by subjecting the cancerous cells to irradiation. This application is similar to the x-ray or radium cancer treatments. However, with the variety of radioactive elements now available, it is sometimes possible to pick an element which will concentrate in a specific place in the body, such as iodine in the thyroid gland. Thus more localized treatment may be possible.

(g) The presence of radiation which will ionize atoms may be useful in speeding up certain reactions.

(h) Reducing the effects of static electric charges.

2. *Tracer Techniques*

The use of the second property depends on the fact that the chemical properties of an atom depend almost completely on the nuclear charge (atomic number) whereas for a given nuclear charge the atomic weight may differ and hence the atom may or may not be radioactive. A typical example is that of the two cobalts, Co^{59} and Co^{60}. Both have the same chemical properties and are inseparable chemically. However, Co^{59} is stable, whereas Co^{60} emits beta and gamma radiation and has a five-year half-life. Hence, Co could be followed or traced through a chemical reaction both quantitatively and qualitatively by mixing a little Co^{60} with the ordinary stable element. Large numbers of radioactive isotopes are now available from the Atomic Energy Commission, the availability having been increased by the advent of the chain-reacting uranium pile with its high neutron flux. It is possible to obtain a radioactive isotope of any stable element. However, the use is somewhat limited by the shortness of half-life of some isotopes and by the low energy of the radiation of some. A comprehensive list of isotopes is to be found in Nuclear Data Circular 499 of the National Bureau of Standards ($4.25).

Because of the great sensitivity of methods of radioactive detection, some of the most obvious applications of tracers are in situations where it is important to know how much material is present when its concentration is extremely minute. Examples are: reactions where freedom from impurities is important such as pigment and ceramic manufacture; the distribution of lubricant on rayon fiber to study its effect in subsequent dyeing and spinning; the effect of minute impurities on the physical properties of synthetic fibers such as manganese in rayon; and wear tests as in gasoline engines.

Other uses are: determination of equilibrium data and operating efficiency in distillation since existing analytical methods in many cases are poor; determination of the homogeneity of mixtures after various amounts of agitation, and of separation efficiencies in centrifuging and filtration especially where finely-divided solids pass through a separation process; study of absorption and adsorption processes.

The commercial availability of the tools needed in this work with radioactive tracers has increased enormously in recent years. In addition to counters and scaling circuits one can obtain lead shields, source holders, automatic sample changers, standard absorbers, standard sources and so on. There is also available a variety of tagged compounds: chemical compounds one of whose atoms is radioactive.

5. HOT LAB INSTRUMENTATION

The problem here is to minimize the hazards to personnel working with radioactive isotopes. Without unduly affecting the ease and efficiency of manipulations each worker must receive less than a certain daily dose of radiation. (See Section 6.)

The intensity of external radiation in the vicinity of a worker may be reduced by shielding and distance. Alpha and beta radiations are stopped by a few thousandths and a few hundredths of an inch respectively of any solid material. Gamma radiation from a 5- or 10-curie source requires about 6 inches of lead or about 18 inches of concrete shielding to enable a worker to remain 3 to 6 feet from the source for about 30 minutes a day. For the more usual samples of 1 to 5 curies, the shielding may have an open top. This permits the use of mirrors and periscopes for visual observation and wide latitude for remote-control manipulations.

Radioisotopes in contact with the skin or mucosa or inside the body, sometimes in amounts as small as 10^{-10} gram, are extremely dangerous because they might not be excreted. Therefore, protective clothing, ventilation, and respirators are also important. All surfaces and equipment should be smooth, hard and streamlined to be readily cleaned. Stainless steel working surfaces and hard tile or removable plastic tape for walls and floors are suitable.

To measure the radiation dose of individuals and to monitor individuals and working areas, various instruments are required as indicated in Table I.

Within the shielding there must be remote control facilities for opening the heavy container and removing the sample, for various manipulations such as pouring, filtering, distilling, making electrical measurements, etc., and eventually for restoring the sample or various fractions of it to containers. The types of such equipment which have been proposed are mechanical, magnetic and hydraulic. They are fairly efficient but much development remains to be done.

6. HEALTH PHYSICS.

The safeguarding of the health of personnel working with nucelar radiation and of the general public is an extremely important aspect of this field of activity. A great deal of instrumentation has already been developed and much is still under development especially in regard to the monitoring of fast neutron intensities. For this latter purpose there are no really satisfactory methods although it has recently been realized that harmful physiological effects are produced by unexpectedly low levels of neutron intensity. A list of types of commercially available monitoring instruments is given in Table I.

There is no level of radiation intensity below which human beings may be said with certainty to suffer no harmful biological effects. In groups of animals (and presumably also people) exposed to a given intensity of radiation there is always a certain fraction which show harmful biological effects. This fraction decreases approximately exponentially with decreasing intensity but never (so far as is known) reaches zero. The "tolerances" which are described below are compromises between safety and practical difficulty in reducing radiation intensities. However, no level of intensity above naturally-occurring background should be tolerated if it can be reduced with reasonable effort and expense. The present accepted tolerance or maximum permissible dose of radiation for humans is 100 millirem per day, although this figure is undergoing revision and 1/2 and even 1/3 of this figure has been suggested.

The rem is that quantity of radiation of any type which produces the same biological effects as one roentgen of x- or gamma rays. The most suitable monitoring instruments (those which do not use G-M. counters) measure the amount of energy lost by radiation in matter. For one roentgen of x- or gamma rays this is approximately 83 ergs in one gram of human tissue. For types of radiation other than these, the quantity of radiation which loses 83 ergs per gram of tissue is called the rep. Thus, by purely physical measurements of energy loss, instruments can be calibrated to read in rep units. The reading in terms of the rem, the unit which is important from a health standpoint, can usually be determined at present only by consulting a table such as the following one:

X-, gamma rays	1 rem = 1 rep = 1 roentgen
Beta particles	1 rem = 1 rep
Alpha particles	1 rem = 0.1 rep
Slow neutrons	1 rem = 0.25 rep
Fast neutrons	1 rem = 0.20 rep

In the light of recent experience it has been suggested that the biological effect of fast neutrons would be better described by defining 1 rem = 0.040 rep. This would correspond to about 400 fast neutrons per sq. cm. per second.

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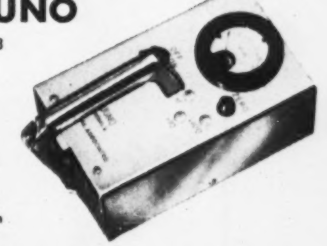

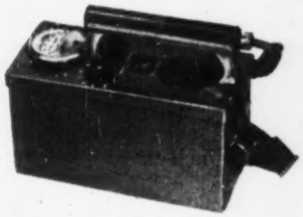

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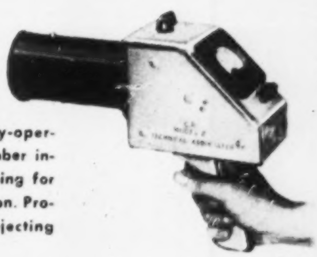

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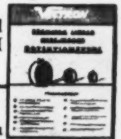

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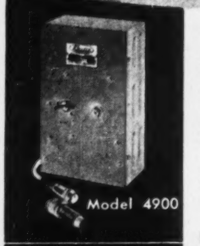

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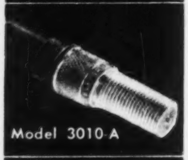

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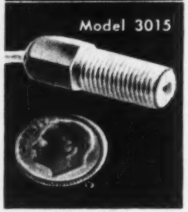

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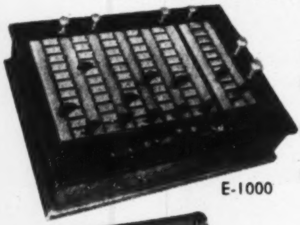

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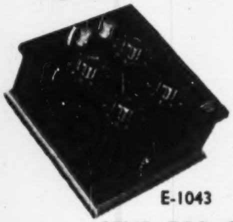

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CHAPTER X

ELECTRICAL INSTRUMENTS AND REGULATORS

By H. N. HAYWARD

FACTORS AFFECTING THE CHOICE OF METHOD AND INSTRUMENTS

MEASUREMENTS should be made by the easiest method and by using the least expensive instruments that will achieve the desired accuracy. However, the mere use of instruments of adequate rated accuracy alone does not insure results of the quality desired. Many precautions must be taken and appropriate techniques used in making measurements in order for the rated accuracy of the instruments themselves to be achieved or even approached in the measured values obtained by using the instruments.

Measurements with indicating instruments, in which the value usually is indicated by the position of a pointer relative to a scale, are generally easiest to make. Many such instruments are available, permitting a wide range of choice of characteristics and accuracy.

The null method of measurement also is widely used, particularly for accurate work, but usually is more difficult and slower than using indicating instruments. In the null method, a form of indicating instrument—the detector—indicates when balance is obtained; but the measurement is made by direct comparison of the unknown with a like or related known value. Potentiometers and bridges are examples of instruments utilizing the null method of measurement.

In a modification of the null method, part of the measurement is made by comparing the unknown with a known value that is variable in fixed steps; and the small difference between the two is measured with an indicating instrument. This method is somewhat less accurate but usually much faster than the null method and is more accurate than using an indicating instrument alone. The deflection potentiometer is the principal example of this type of instrument.

Measurables that are not changing too rapidly to be accurately followed may be measured with recording (graphic) instruments. Some recorders operate like indicating instruments but require more power. Others, including many industrial recorders, operate on the null principle. Values changing more rapidly may be measured, observed or recorded with an oscillograph. Measurement of certain electrical variables integrated with respect to time is accomplished with an electricity meter, of which the watthour meter for the measurement of electric energy is an important example.

A wide variety of instruments may be used for making certain measurements, particularly of voltage, current and resistance. Each type of instrument has certain advantages and some limitations and may be adaptable for particular applications. The usual application ranges of instruments and their general field of use are listed in Chart I for voltage measurements, in Chart II for current measurements and in Chart III for resistance measurements. Not all the instruments listed can be described because of space limitations. Most power measurements are made with wattmeters of the electrodynamic type, usually with an air core, although some have an iron core. Induction wattmeters also are still used to some extent. Thermal wattmeters find application in the utility industry, particularly as demand meters and load totalizers. Decibel (DB) meters, VU meters, or volume indicators used in communication work for power measurements usually are rectifier type voltmeters connected to measure the voltage across a fixed resistance load, the calibration being based on the fact that the power in a resistance equals E^2/R.

The selection of an instrument involves much more than merely choosing one operating on a suitable principle and having the desired range. The quality of the components used, features of electrical and mechanical design, and the workmanship largely determine the accuracy and serviceability of an instrument. This requires some knowledge and understanding of and experience in using an instrument and others like it before an individual really is capable of making a good choice.

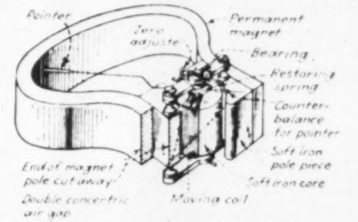


Fig. 1. Conventional permanent-magnet moving-coil instrument reads average value of pulsating voltages or currents. Frequently magnetically shielded by placing in a soft-iron or steel cylinder.

INDICATING INSTRUMENTS

General. With the exception of electrostatic instruments, indicating instruments depend on electromagnetic effects for their operation and are "current sensitive." Basically then, an instrument to measure other than current must be designed so the deflection of the pointer will be proportional to the variable to be measured. In addition, certain features may be necessary within the instrument to compensate for the effects of temperature and other influences to which the instrument may react. Some effects cannot be compensated for within the instrument, and must be controlled by the user. One of these is the position in which an instrument is used. The normal position for panel and switchboard instruments is vertical and for portable instruments is horizontal. *The accuracy rating of an indicating instrument applies only when it is used in the normal position.*

Accuracy Rating. The accuracy rating classifies an instrument in terms of accuracy; it states the maximum error allowable in a new instrument under certain specified conditions. The accuracy usually is expressed in percentage, as 0.5 percent; and "percent" always refers to the total scale length. For instruments with the zero not at one end of the scale, the scale length is the sum of the end scale values to the right and left of the zero. This accuracy rating in terms of total scale length is defined somewhat differently for uniform scales and for nonuniform scales. The indication of a 0.5-percent ammeter having a uniformly-divided 100-division scale and a range of 1 ampere should be within 0.5 scale division or 0.005 ampere (equivalent to 0.5 percent of the scale length) of the correct pointer position anywhere on the scale. A 0.5-percent instrument having the same range and number of scale divisions but with a nonlinear scale should indicate within 0.5 scale division or 0.005 ampere the correct pointer position on all the scale divisions that are ⅔ or more of the width they would have if the scale were uniform. This would allow a maximum difference of 0.33 percent of the scale length between the actual pointer location and the correct position for the divisions that are ⅔ the width of a division of a corresponding uniform scale. This same tolerance of 0.33 percent of the total scale length also applies (for a 0.5-percent instrument) to all the scale divisions less than ⅔ the width of those in a uniformly-divided scale, making the permissible error in percentage of the electrical full-scale range larger than the percentage accuracy rating of the instrument for any portion of the scale in which the width of a scale division is less than ⅔ the width of a division of an equivalent uniformly divided scale. If an instrument has a scale that is seriously crowded over a portion of its length, the actual permissible error on that part of the scale will be considerably greater than is apparent from the accuracy rating of the instrument.

The actual accuracy may be somewhat better than the rated accuracy, but neither the actual nor the rated accuracy includes the reading error resulting from estimating the position of the pointer when not exactly over a scale division line. The reading error alone will make the working accuracy from 0.1 percent to perhaps 0.25 percent poorer than the anticipated accuracy. The magnitude of the reading error will depend on the length of the scale divisions, the observer and other factors.

Factors Affecting Accuracy. In addition to the position influence already mentioned, other factors which may increase the error to a value greater than indicated by the accuracy rating are (1) the external temperature, (2) the internal heating and other effects of sustained operation, (3) external magnetic fields and (4) the location of magnetic materials near the instrument. Some instruments (other than voltmeters) having voltage circuits may be influenced by a change in voltage; others (excepting frequency meters) may be influenced by frequency; and still others (wattmeters and varmeters) may have their accuracy influenced by the power factor of the circuit. Interelement influence usually is present in such instruments as polyphase wattmeters.

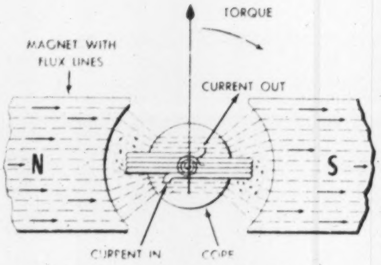


Fig. 2. Deflection of pointer of permanent-magnet moving-coil instrument is caused by interaction of fields.

If the value being measured is varying in magnitude sufficiently to cause the instrument pointer to fluctuate perceptibly, it is impossible to assign a definite value to the reading or to the accuracy with which it is known.

The accepted definitions of accuracy rating and of the various influences affecting accuracy, also of many other terms relating to indicating instruments, will be found in the "American Standard for Electrical Indicating Instruments, C39.1-1951" published by the American Standards Association.

CHART I—APPLICATION RANGES OF INSTRUMENTS FOR VOLTAGE MEASUREMENT

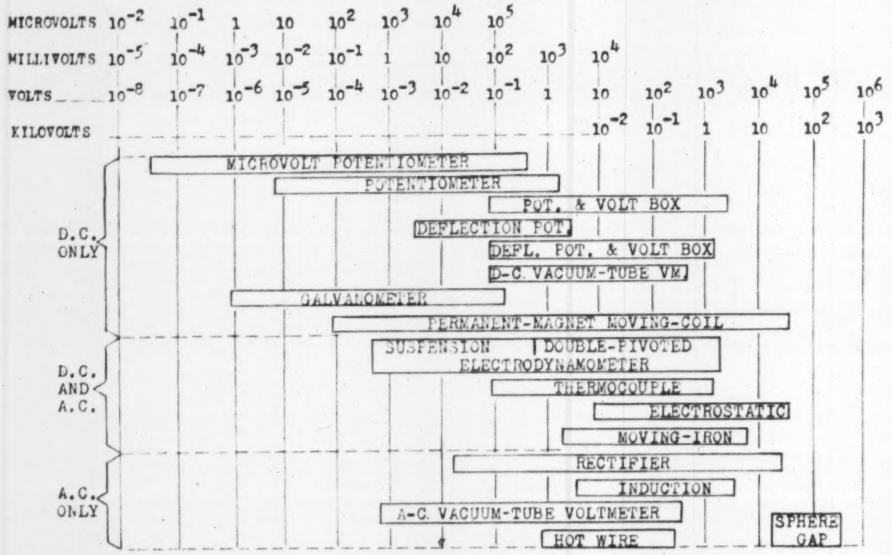


CHART II—APPLICATION RANGES OF INSTRUMENTS FOR CURRENT MEASUREMENT

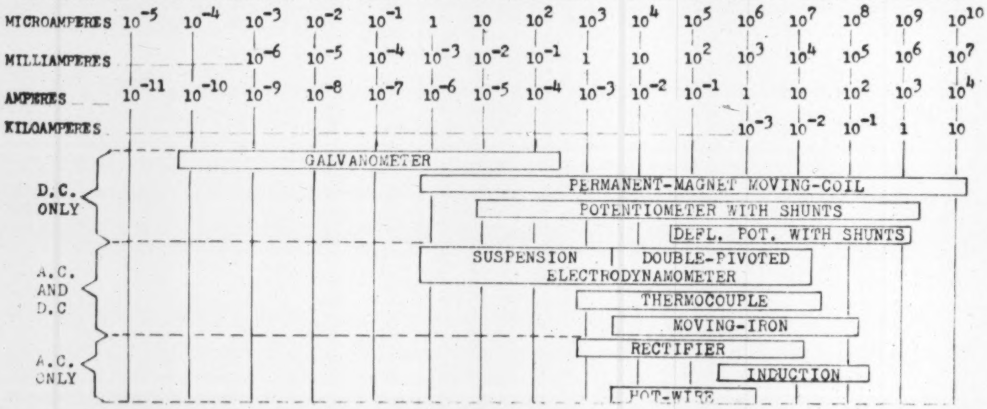
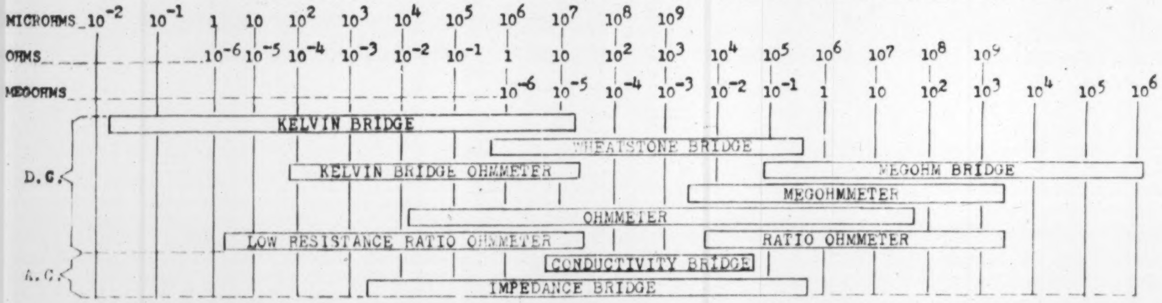


CHART III—APPLICATION RANGES OF INSTRUMENTS FOR RESISTANCE MEASUREMENT



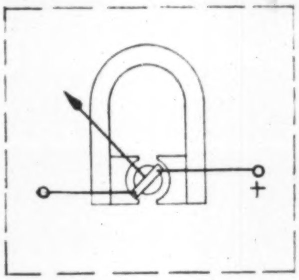


Fig. 3. Unshunted microammeter or milliammeter.

Resetting the pointer on zero does not always insure that an instrument will read correctly. An off-zero pointer is frequently an indication of damage.

Single-range vs Multirange Indicating Instruments. There is seldom need for other than single-range panel or switchboard instruments, as each one usually is connected permanently in a circuit. But with portable and test instruments, the total cost of covering the required range of measurement is reduced and fewer separate instruments are required if multirange instruments are used. Maximum economy and convenience, however, probably will not result from the selection of the smallest number of instruments with each having the maximum possible number of ranges. Double- or triple-range instruments frequently will be most adaptable for general use. Range ratios of 1:2, 1:2.5 or 1:5 usually are best for double-range instruments and 1:2:4, 1:2:5, 1:2.5:5 or 1:2.5:10 ratios are generally preferred for triple-range instruments. With these ratios, the overlap is sufficient to permit good measurements to be made anywhere between 25 percent of the lowest range and the limit of the highest range.

TYPES OF INSTRUMENTS

Polarized Iron-vane Mechanism. The polarized iron-vane (or moving-magnet) mechanism is used only in small, relatively inexpensive d-c. instruments. The polarized vane (permanent magnet), making up the moving system with the shaft and pointer, aligns itself with the field of the stationary control magnet when there is no current in the coil. Current in the coil establishes a second magnetic field varying with the current and displaced in direction from the control field. The direction of the resultant field thus varies with the current in the coil. The polarized vane will align itself with the resultant field, causing the deflection of the pointer to vary with both the magnitude and direction of the current in the coil.

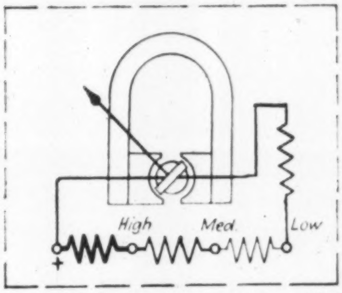


Fig. 5. Multirange microammeter, milliammeter, or ammeter.

Permanent-magnet Moving-coil Mechanism. The basic permanent-magnet moving-coil mechanism shown in Fig. 1, frequently in modified form, is utilized in all but the most inexpensive d-c. instruments, and in all a-c. thermocouple and rectifier instruments and vacuum-tube voltmeters. The usual scale arc is about 90 degrees. To obtain a longer scale without increasing the panel area required, circular or concentric-scale instruments have become available in which the scale arc is about 270 degrees.

The operation of the permanent-magnet moving-coil instrument depends on the interaction of the current in the moving coil and the field in the air gap maintained by the permanent magnet. A conductor carrying current across a magnetic field will have a force exerted on it in a direction toward the side of the conductor where the field produced by the current and the main field are in opposite directions, as shown in Fig. 2. The resulting torque tending to rotate the coil is directly proportional to the current in the coil. The springs provide a restoring torque proportional to the angle of deflection, so the coil will turn through an angle proportional to the current before opposing torques balance and the moving system comes to rest. By the use of a pointer attached to the coil and a fixed scale properly calibrated, this mechanism can be used to measure current or *any variable that can be converted into a proportional current.* It is the most sensitive electrical indicating mechanism. The most sensitive double-pivoted mechanism available requires less than 0.1 microwatt for full-scale deflection.

The circuit of an unshunted microammeter or milliammeter, in which the total current to be measured passes through the moving coil, is given in Fig. 3. The addition of a *series* resistor, as shown in Fig. 4, converts the instrument into a millivoltmeter or voltmeter. The further addition of a *parallel* resistor, called a shunt, to a millivoltmeter, as shown in Fig. 5, increases the range of the unshunted instrument and converts the microammeter or milliammeter into an ammeter. The combination of a millivoltmeter (Fig. 4a) with calibrated leads and an external 4-terminal shunt, as shown in Fig. 6, is used to make up ammeters of any required range up to several thousand amperes. Data on the most sensitive full scale ranges and corresponding loss requirements are given in Table I.

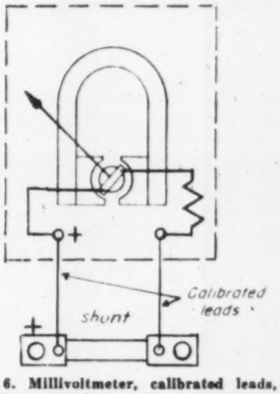


Fig. 6. Millivoltmeter, calibrated leads, and external 4-terminal shunt for measuring current.

The Moving-iron Mechanism. Most a-c. voltmeters and ammeters for use at power frequencies utilize a moving-iron mechanism, which is available in several forms. One is the inclined coil and vane mechanism, although most moving-iron instruments utilize a repulsion mechanism consisting of one fixed and one moving vane magnetized by one coil. The vanes repel each other when so magnetized in accordance with magnetic principles. One repulsion mechanism that is generally used has

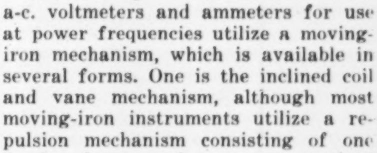

Pointer
Truss construction
Pivot
Spiral restoring spring
Aluminum vane housed in air chamber provides damping
Adjustable counter balances
Current
Stationary flat soft iron piece
Field coil
Soft iron vane free to rotate
Pivot

Fig. 7. Radial-vane moving-iron repulsion mechanism.

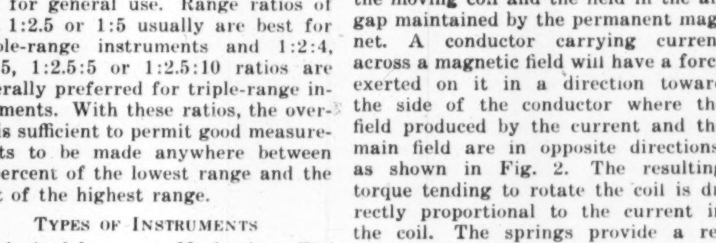


Fig. 4. Millivoltmeter or voltmeter. A, single range (left); B, multirange (right).

concentric vanes which can be shaped to give special scale characteristics. Recent improvement in magnetic materials has been one factor in the development of the radial-vane repulsion mechanism illustrated in Fig. 7. An advantage of this type is the almost uniform scale. All these instruments will have scales about 90 deg. in length. On circular-scale switchboard instruments having 240-deg. scales, a combination repulsion and attraction mechanism is used to obtain the long scale.

A resistor is connected in series with the instrument coil to make a voltmeter, the same as for a d-c. voltmeter, except that in the moving-iron instrument the coil is stationary and no electrical connection to the moving element through the spring is necessary. The coil of some moving-iron ammeters may be wound for currents as large as 500 amp., although ranges greater than 5 amp. frequently are obtained with 5-amp. instruments and current transformers. Data on the most sensitive full-scale ranges of moving-iron instruments and corresponding loss values are given in Table II.

The most sensitive moving-iron instrument requires about 0.15 watt for full scale deflection. This is about 1,500,000 times the power required for the most sensitive d-c. instrument and explains some of the difficulties encountered in attempting to make measurements of small alternating currents or voltages.

The Electrodynamic Mechanism. This is perhaps the most versatile and important type of a-c. instrument mechanism. Electrodynamic voltmeters, ammeters and wattmeters serve both as transfer standards calibrated on direct current and used on alternating current to calibrate other instruments and to make precision a-c. measurements at power and low-audio frequencies. Reference here is to the air-core mechanism. The arrangement of the basic parts of an electrodynamic mechanism is shown in Fig. 8.

Connecting the fixed and moving coils in series adapts the mechanism to the measurement of currents of the order of several milliamperes. The addition of a series resistor adapts the mechanism to the measurement of voltage. The addition of both a shunt resistor in parallel with the moving-coil circuit and a resistor in series with the moving coil makes possible ammeter ranges up to several amperes.

Except for the induction and thermal types, wattmeters for the measurement of power utilize the electrodynamic principle. The field winding of Fig. 8 becomes the current coil and the armature winding becomes the potential coil which is connected in series with a resistor to make up the potential circuit. Wattmeter and other instrument connections will be considered in later sections. Data on the most sensitive full-scale ranges and corresponding loss values are given in Table II.

The most sensitive double-pivoted electrodynamic mechanism requires about 0.4 watt for full-scale deflection, which is 4,000,000 times the power required for a sensitive d-c. mechanism of comparable accuracy. An iron-core electrodynamometer is more sensitive but less accurate than the one utilizing an air core and is used in some switchboard and small voltmeters and wattmeters.

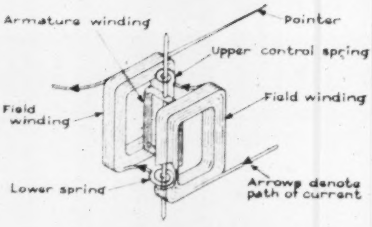


Fig. 8. Components of electrodynamic mechanism. Current in fixed coils (labeled field winding) provides the flux with which the current in the moving coil (labeled armature winding) reacts to develop torque in the same manner as explained for the permanent-magnet moving-coil mechanism. If the currents in both the fixed and moving coils are reversed, the torque remains in the same direction as before, making it possible to use this mechanism for a-c. measurements. As torque is proportional to the average of the product of the currents in the fixed and moving coils, this mechanism measures effective (rms) values of a. c.

Rectifier Instruments. These consist of a permanent-magnet moving-coil d-c. mechanism combined with a dry-type rectifier and resistance network and are the most sensitive a-c. instruments for measuring current and voltage. A bridge-type full-wave rectifier may be used and it is connected as shown in Fig. 9. The basic instrument is a milliammeter or microammeter, series resistors being used to increase the voltage range and shunts or a current transformer to obtain higher current ranges. Lowest voltage ranges are limited by the nonlinear resistance characteristics of the rectifier, but millivoltmeter ranges may be obtained by using a step-up potential transformer to multiply the voltage actually impressed on the rectifier and instrument.

The deflection is proportional to the average current or voltage but the instrument is scaled to read effective (rms) values, so will read correctly (within rated accuracy) only on sine waves, which have a form factor (ratio of effective to average value) of 1.11. Readings will be high on flat-topped waves (11 percent on a square wave, which has a form factor of 1.0) and low on peaked waves by the amount the form factor of the measured wave is less or more than 1.11. Data on the most sensitive full-scale ranges and corresponding loss values are given in Table II.

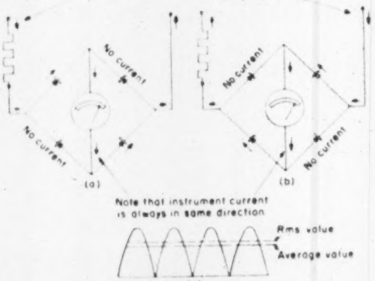

During these half-cycles current flows through circuit in this direction
During these half-cycles current flows through circuit in this direction
No current
No current
No current
No current
(a)
(b)
Note that instrument current is always in same direction
Rms value
Average value
(c)

Fig. 9. Schematic diagram and principle of operation of rectifier voltmeter.

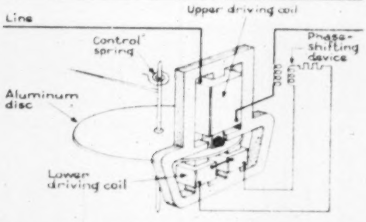


Fig. 10. Schematic diagram of induction ammeter circuit and parts. The shifting magnetic field required for operation is supplied by magnetic circuit design and phase shifter which couples the two driving coils. Eddy currents induced in the disk by the changing flux react with the flux to develop torque on disk in direction that field advances. Disk rotates until torque is balanced by control spring.

Induction Instruments. Although many are still in use, induction voltmeters, ammeters, wattmeters and frequency meters have been rather generally superseded by other types. As applied in a-c. ammeters, the principle of operation is illustrated schematically in Fig. 10. Induction instruments will not operate on direct current and the voltmeters, ammeters and wattmeters must be calibrated and used at the same frequency or a correction applied. An ammeter or wattmeter current coil would be undamaged by connection to a d-c. circuit if not overloaded, but a voltmeter or wattmeter potential coil would burn out quickly.

The principal advantage is the long scale that is possible, theoretically a full 360 degrees. The principal disadvantages are the inherent frequency error (of all but the frequency meter), which cannot be compensated for, and the temperature error, which is difficult to compensate for.

Vacuum-tube Voltmeters. The calibration of these instruments may not be stable and their accuracy is less than most indicating instruments, with the possible exception of rectifier instruments. They usually are scaled to read in effective (rms) values, so will be within normal accuracy limits only on sine waves.

Thermocouple Instruments. A permanent-magnet moving-coil instrument is used with a thermocouple-heater element to measure current, as shown in Fig. 11. Only the heater is in the electric circuit in which the measurement is made. The heating produced by the I^2R power in the heater raises the temperature of the thermocouple junction in contact with the heater above

TABLE I—DIRECT-CURRENT INDICATING INSTRUMENTS
Permanent-Magnet Moving-Coil Mechanism

Grade or Class	*Accuracy, % of Full Scale*	*Scale Length, Inches*	*Approx. Cost for Single Range*	*Minimum Full-Scale Range and Corresponding Loss (note w)*					
					Micro-amperes	*Milli-amperes*	*Amperes (i)*	*Milli-volts (g)*	*Volts*
Laboratory Standard (notes a ,e, f)	1/10	11–12.5 Usually Vernier	$250 to $640	Range Loss		10 (h) 100 mv.	1 (h) 100 mv.	50 25 ma.	1.5 5 ma.
Precision Portable (notes b, f)	0.2–0.3	5.2–6.5	$80 to $155	Range Loss	50 75 mv.	1 100 mv.	1 50 mv.	10 2.5 ma.	0.5 1 ma.
Portable (notes b, f)	0.5–0.75	3.5–6.1	$25 to $195	Range Loss	2 35 mv.	0.1 4 mv.	1 50 mv.	1 0.2 ma.	1 1 ma.
Small Portable (note b)	1–2	2.3–4	$15 to $60	Range Loss	20 20 mv.	1 55 mv.	1 50 mv.	10 0.4 ma.	1 1 ma.
Panel (note c)	1.5–2	1.1–4.75	$5.50 to $50	Range Loss	10 40 mv.	1 25 mv.	1 50 mv.	10 2 ma.	1 1 ma.
Switchboard **(note c)**	1	3.3–7.3	$30 to $110	Range Loss	15 100 mv.	1 70 mv.	1 50 mv.	10 0.4 ma.	1 1 ma.

NOTES FOR TABLES I AND II

NS Loss not stated by manufacturer.

(a) Must be leveled.

(b) Accuracy rating applies only with instrument horizontal.

(c) Accuracy rating applies only with instrument vertical.

(d) Calibration usually dependent on whether mounted on magnetic or nonmagnetic panel.

(e) Some should be oriented in earth's or local field.

(f) Corrections for ambient temperature, self-heating and external fields frequently necessary to achieve nominal accuracy.

(g) Because of low instrument resistance, calibration of d-c. millivoltmeters and ammeters with separate shunts and low-range a-c. voltmeters is affected by lead resistance so these instruments should be calibrated and used with the same leads.

(h) Each range usually obtained with separate external shunt. See note g.

(i) Ammeters may be self-contained (internal shunts) to 50 or more amperes, higher ratings with external shunts. For use with external shunts, see note g regarding instrument leads.

(j) Use limited to direct current (average of reversed polarity readings) and 25 to about 125 cycles.

(k) Use limited to direct current (average of reversed polarity readings) and 25 to about 125 cycles unless compensated for higher frequencies. Voltmeters may be compensated to 2500 cycles, ammeters to 1000 cycles (2500 with reduced accuracy), wattmeters to 1000 cycles (except less for low potential ranges) or 2500 cycles with reduced accuracy.

(l) Use limited to 25 to about 125 cycles, except some milliammeters and ammeters to 500 cycles, unless compensated. Compensation (with increase in loss) to 1000 cycles sometimes possible or to 2500 cycles (with reduced accuracy).

(m) Usually limited to about 5000 cycles (15000 in some cases).

(n) Some portable instruments limited to 15000 cycles, most others good to about 300 megacycles.

(o) Usually good to 50 megacycles, higher with reduced accuracy.

(p) Measure effective (rms) values, regardless of wave form, with minimum error.

(q) Pointer deflection proportional to average value but usually scaled in effective (rms) values. Within nominal accuracy only on sine waves. Usually limited to 20000 cycles or less but some may be used to 100 kc.

(r) 60 cycles only.

(s) 25 to 100 cycles

(t) 50 to 100 cycles.

(u) Some with iron core limited to single frequency only between 25 and about 125 cycles, others operate at any frequency within these limits.

(w) Loss of a current circuit is voltage drop at full-scale current and of a voltage circuit is current at full-scale voltage.

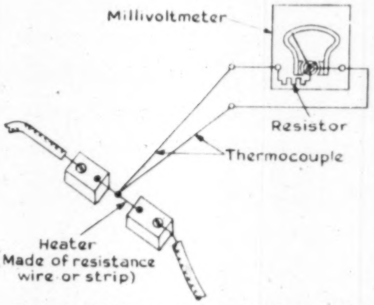


Fig. 11. Schematic diagram of thermocouple ammeter.

that of the other junction. This difference in temperature results in different thermal emf's at the two junctions and establishes current in the closed instrument circuit that is proportional to the temperature difference. The resultant instrument deflection is proportional to the square of the effective value of current in the heater, so by proper calibration the readings will be in effective (rms) values, regardless of the wave-form of the current in the heater.

Adding a resistor in series with the heater makes it possible to measure voltages. The upper frequency limit for which good accuracy can be maintained for thermocouple voltmeters is determined by the characteristics of the series resistor and usually will be approximately 15 or 20 kilocycles.

The most sensitive thermocouple milliammeters require about 2.5 milliwatts for full-scale deflection, which is about 25,000 times the power required for the most sensitive d-c. instrument of comparable accuracy. A minimum of about 10 milliwatts is required for a thermocouple voltmeter. Sensitivity data are given in Table II.

Electrostatic Instruments. These are the only instruments that are directly voltage sensitive and do not depend on a current for their operation. Although electrostatic instruments are used for other measurements also, voltmeters are the most common form. They consist essentially of two sets of plates as shown schematically in Fig. 12, one movable and one fixed as in a variable capacitor, with the moving system of very light construction. The voltage to be measured is applied between the plates, which will acquire a charge that is proportional to the potential difference or voltage. As the charge will be of opposite sign at any instant, there will be a force of attraction between the plates. This force will cause the movable plates and pointer to move until the deflecting force is balanced by a spring or other restoring force. Because the deflecting force is proportional to the square of the voltage between the plates, these instruments will measure effective (rms) voltages. For a-c. measurements, the charging current will vary directly with the frequency and will become appreciable at radio frequencies. The advantages

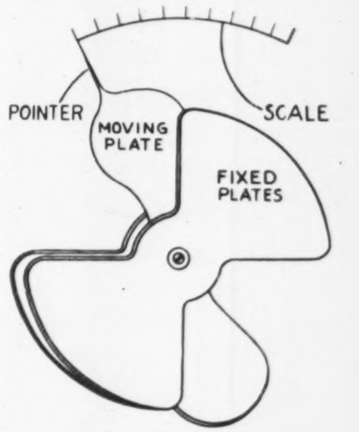


Fig. 12. Early electrostatic mechanism developed by Lord Kelvin about 1887. Some of similar construction are still in use.

TABLE II—ALTERNATING-CURRENT INDICATING INSTRUMENTS

Grade or Class	*Accuracy, % of Full Scale*	*Scale Length, Inches*	*Type of Mechanism*	*Approx. Cost of Single Range*		Minimum Full-Scale Range and Corresponding Loss (note w)								
						Micro-amperes	*Milli-amperes*	*Amperes*	*Milli-volts*	*Volts*	*Single-phase Wattmeter*		*Polyphase (Two-element) Wattmeter*	
											Volts	*Amperes*	*Volts*	*Amperes*
Laboratory Standard (notes a, b, f, j)	0.1	12	Electrodynamometer	$270 to $900	Range Loss		250 46 v.	0.5 20 v.		75 86 ma.	75 46 ma.	0.5 2 v.		
Precision Portable (notes b, f)	0.2–0.3	5.25 to 6.5	Electrodynamometer (k)	$115 to $225	Range Loss		5 9 v.	0.5 9.4 v.		3 (g) 500 ma.	50 22 ma.	0.5 1.8 v.		
		6.5	Moving-iron (l)	$125 to $170	Range Loss			0.25 7.2 v.						
Portable (notes b, f)	0.5–0.75	3.2 to 5.5	Electrodynamometer (k)	$60 to $400	Range Loss		50 20 v.	0.5 1.2 v.		1 (g) 500 ma.	50 10 ma.	0.1 7 v.	50 26 ma.	2.5 0.4 v.
			Moving-iron (l)	$25 to $85	Range Loss		5 20 v.	1 0.12 v.		1 (g) 570 ma.				
	0.5–1.5	3.2 to 6.1	Thermocouple (p)	$40 to $300	Range Loss		1.5 (n) 2.25 v.	0.5 (o) 0.42 v.		0.2 (m) 10 ma.				
	1.5	4 to 5.5	Rectifier (q)	$100 to $200	Range Loss					75 1 ma.				
	4	4	Rectifier (q)	$130	Range Loss				25 (r) NS					
Small Portable (note b)	1–2	2.7	Iron-core Electrodynamometer	$70 to $150	Range Loss			1 (t) 70 mv.		1 (s) 48 ma.				
		1.6 to 3.5	Moving-iron (l)	$8.50 to $35	Range Loss		5 30 v.	0.5 0.35 v.		1.5 (g) 300 ma.				
	2–3	2.4 to 2.8	Rectifier (q)	$24 to $60	Range Loss	200 0.4 v.	0.5 0.35 v.			2 1 ma.				
Panel (notes c, d)	1–2	2.6 to 3.25	Electrodynamometer (k)	$17 to $100	Range Loss						150 NS	0.75 NS	150 NS	0.75 NS
	1.5–2.0	1.5 to 3.2	Moving-iron (l)	$5.50 to $30	Range Loss		5 32 v.	1 0.2 v.		1.5 (g) 333 ma.				
	1–2	1.6 to 4.75	Thermocouple (p)	$6.75 to $70	Range Loss		10 (n) 0.85 v.	1 (o) 0.2 (v)						
	5	1.6 to 3.5	Rectifier (q)	$16 to $50	Range Loss	100 0.32 v.	0.5 0.52 v.			1 0.5 ma.				
Switchboard (note c)	1	5.1 to 7.1	Air- or Iron-core Electrodynamometer (u)	$45 to $170	Range Loss						120 20 ma.	1 0.7 v.	120 17 ma.	1 2.6 v.
		4 to 7.5	Moving-iron (l)	$30 to $80	Range Loss		10 22 v.	1 0.32 v.		1.5 (g) 300 ma.				

of electrostatic instruments are greatest on direct current and at power frequencies, because of the negligible current requirements, particularly for high voltage applications.

Power Factor Meters. Instead of the power, it frequently is desirable to know the power factor, which is the ratio of true power (watts) to apparent power (volt-amperes) in an a-c. circuit. Power factor meters of the electrodynamic type, similar to wattmeters, but with two moving coils (displaced about 90 deg.) instead of only one, may be used (with appropriate connections) on either single-phase or three-phase circuits. Another type of power factor meter utilizes a polarized-vane mechanism. Power factor meters, like wattmeters, have both potential and current circuits. Single-phase instruments are adjusted for a single fixed frequency only and their indications will be in error at other than the normal frequency. Three-phase instruments are free of the frequency error of single-phase instruments but will indicate correctly only on balanced systems.

Synchroscopes. By changes in construction and connections, the crossed-coil electrodynamometer or the polarized-vane mechanism may be utilized in synchroscopes, which are instruments used to indicate when two a-c. circuits or machines are in phase so they may be paralleled. There are other types of synchroscope mechanisms also. Unlike other instruments, the moving element of a synchroscope is free to rotate continuously, thus indicating a difference in frequency. Synchroscopes have two potential circuits only. One is connected to the system and the other to the incoming unit that is to be synchronized.

Frequency Meters. Several types of instruments are used to measure frequency (the number of cycles per second in an a-c. circuit): the vibrating-reed type, the crossed-coil iron-vane ratio type, the resonant-circuit electrodynamometer type or the induction type. They are operated by a potential circuit when connected to a line of suitable voltage.

MISCELLANEOUS INSTRUMENTS AND METERS

Recorders. A great variety of recorders is available, some with round charts for making daily records and others with strip charts for making continuous records over long periods. Some charts are drawn with ink, on others an inkless record is made. Permanent-magnet moving-coil, moving-iron and electrodynamic mechanisms similar to but larger than those in indicating instruments are used in recorders, which require more power for operation than is needed in indicating instruments. Amplifiers are available to permit the recording of variables too small to permit the operation of a recorder directly. Self-balancing potentiometric recorders that are also self-standardizing are in general use, some of which may make records of several variables by measuring each one in succession. Self-operating bridge-type recorders are also available. Potentiometric, bridge-type and photoelectric recorders require little power from the circuit in which the measurement is made, so may be adapted to many special applications.

Oscillographs. These may be divided into direct-writing, magnetic and cathode-ray types. Direct-writing oscillographs utilize a powerful galvanometer to drive the pen that traces the wave, so usually include an amplifier to provide the power that is needed and are limited to low frequencies. Magnetic oscillographs utilize light beam galvanometers and may be used to record waves of voltage, current or power up to frequencies of a few thousand cycles per second. Multi-channel direct-writing and magnetic oscillographs are available, permitting several traces to be recorded simultaneously. Cathode-ray oscillographs are perhaps the most versatile of all and will operate over a wide frequency range, some up to very high frequencies in the megacycle range. Usually, only a single trace can be viewed or recorded. As is true of all instruments, these can not be relied upon to operate indefinitely without care and maintenance.

Instrument Transformers. Current transformers permit the use of instrument current circuits rated at 5 amp. (sometimes 1 amp.) for making measurements involving larger a-c. currents and also insulate the instrument circuit from the other, which often is at a high voltage. Similarly, potential transformers are used to permit 150-volt instrument potential circuits to be used in all cases where the voltage is over 750 volts and also insulate the instrument circuit from the other. (Resistance multipliers may be used below 750 volts.) As the secondary circuits of instrument transformers are normally grounded, the primary insulation should be tested before use to insure that the transformer will not ground the primary circuit. The primary and secondary terminals of instrument transformers are marked to indicate their relative polarity and the instruments are connected in the secondary circuit in the same way that the transformer primaries are connected in the power circuit to maintain the correct relative polarities between the primary and secondary circuits.

The ratio of instrument transformer primary to secondary values does not remain constant for all conditions, but deviates sufficiently from the nominal ratio to affect some voltage and current measurements. This error is corrected for by multiplying the instrument reading by the nominal transformer ratio (primary to secondary voltage or current) and by the ratio correction factor (RCF) for the transformer determined by calibration for the particular conditions involved.

The secondary current or voltage of an instrument transformer is displaced slightly in phase from the corresponding primary value and this displacement is called the phase angle of the transformer. This phase angle is determined by calibration and, although small, introduces an additional error in power and other measurements involving both current and potential circuits and may have to be corrected for, particularly when the power factor is low.

The secondary circuit of a current transformer should never be opened when there is current in the primary. The secondary should be short circuited before removing instrument or other connections and left short circuited until after normal connections are restored.

Watthour and Reactive Volt-ampere hour Meters. As most electric energy is metered in a-c. circuits, the induction watthour meter is the type in greatest use. The construction is similar to that of the induction instrument in Fig. 10, with the connections changed to those of a wattmeter, except that the disk may rotate continuously. The disk drives a register whose reading is proportional to the total number of revolutions of the disk. As the disk makes one revolution each time a given amount of energy is supplied to the load side of the meter, the register reading multiplied by an appropriate constant shows the total energy supplied and the difference between the present and previous readings is the energy supplied since the previous reading. All electric energy bills are rendered on the basis of these meter readings, but some may also take other factors into account.

If the voltage impressed on the watthour meter potential circuit is displaced by 90 deg. from the normal for which it will measure electric energy, it becomes a reactive volt-ampere hour meter and measures the net lagging reactive volt-ampere hours supplied to a load. The disk will rotate in the normal direction for lagging power factor and in the reverse direction for leading power factor. Special autotransformers are used in three-phase circuits to provide the displaced voltages needed for reactive metering. Metering circuits may be very complex so must be set up very carefully to insure proper operation of the meters.

All energy meters have a light load adjustment, primarily to compensate for friction, and a heavy load adjustment to insure accurate registration under normal load. Modern meters are reasonably free of temperature and other influences that will appreciably affect their registration under the usual range of operating conditions.

INSTRUMENT CONNECTIONS

General. The internal circuits of electrical instruments are basically of two types. Voltmeters and the potential circuits of other instruments are of relatively high resistance or impedance and are to be connected between the lines or across a circuit element between the points where the voltage exists that is to be measured or is

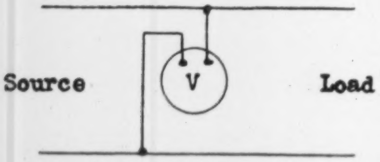


Fig. 13a. Voltmeter and instrument potential-circuit connection. To read line voltage, connect one of the terminals to one line and the other terminal to the other line.

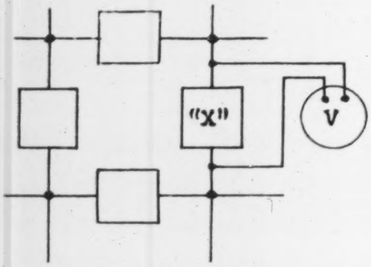


Fig. 13b. Voltmeter and instrument potential-circuit connection. To read the voltage of circuit element "X," connect one instrument terminal to one terminal of "X" or to one of the connections between "X" and the first junction with other leads. Connect the other terminal of the instrument to the second terminal of "X" or to the connection between that terminal of "X" and the nearest junction with other leads.

involved in the measurement, as shown in Fig. 13. The voltage applied to the instrument must not exceed the rating of the potential circuit or it will be overheated and damaged. Ammeters and the current circuits of other instruments are of relatively low impedance or resistance and are to be connected in a line wire or lead to a circuit element in which the current exists that is to be measured or is involved in a measurement, as shown in Fig. 14. The current must not be greater than the current rating or the circuit will be overheated and damaged.

The polarity of the terminals of d-c. instruments usually is marked and must be observed when connecting these instruments in a circuit. The + terminal of a d-c. voltmeter and of a d-c. ammeter must be connected to the + line so the direction of current through the instrument will be from + to − for the pointer to deflect upscale. There is no polarity reference for a-c. voltmeters and ammeters but the relative polarity of the current and potential circuits of instruments having both must be correct for the instruments to operate properly.

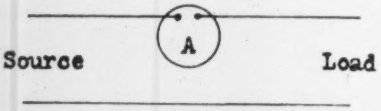


Fig. 14a. Ammeter and instrument current-circuit connection. To read current in line, break the line (with the power disconnected) and insert instrument in series with the line.

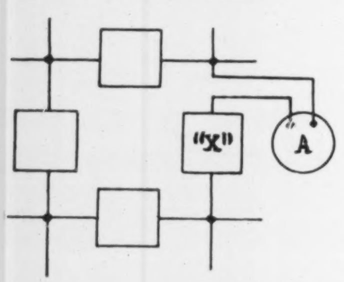


Fig. 14b. Ammeter and instrument current-circuit connection. To read current in circuit element "X," break one of the connections between "X" and the first junction with other leads and insert instrument in series with "X."

Wattmeter Connections. The wattmeter potential terminal connecting to the resistance in the potential circuit should connect to the line on the side of the load away from the wattmeter current coil The other potential terminal, connecting to the moving coil and usually marked ±, should connect to the line in which the current coil is connected. This will insure that there is no difference in potential between the two coils in the instrument. If the potential connections were reversed, the potential and current coils would differ in potential by the line voltage and this might cause considerable error in the reading. The current coil should be connected so the pointer deflects upscale. If one terminal is marked ±, it usually will be connected to the line. Wattmeters may be connected in either of the ways shown in Fig. 15. If the load is small, the power loss in the wattmeter current coil should be subtracted from the reading for the connection shown in (a) or the power loss in the wattmeter potential circuit subtracted from the reading for the connection shown in (b) to obtain the actual power in the load.

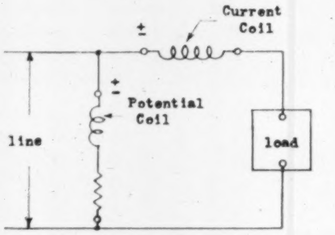


Fig. 15a. Wattmeter potential connection on line side of current coil.

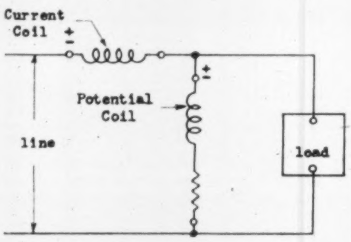


Fig. 15b. Wattmeter potential connection on load side of current coil.

Connections for two wattmeters or a two-element polyphase wattmeter in a three-wire circuit are as shown in Fig. 16. The current coils of the two-element wattmeter should be connected so each element will deflect the pointer upscale when that element alone is connected in a two-wire circuit as shown in Fig. 15. This will insure that the wattmeter is correctly connected in the three-wire circuit. If separate wattmeters are used, one of them may read negative (even on a balanced three-phase load), so the actual power is the difference between the readings of the two instruments instead of their sum. A full explanation cannot be given here, but no one should attempt to measure the power in a three-wire (or four-wire) circuit who does not understand how to make the connections and check the signs of the wattmeter readings.

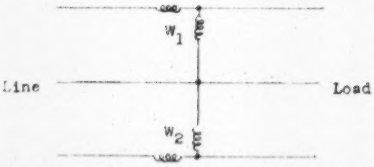


Fig. 16. Connection of two wattmeters or a two-element wattmeter in a three-wire circuit.

INSTRUMENT CHECKING

Why Checking Is Necessary. Some new instruments may not meet accuracy rating or other specifications. Furthermore, accuracy is not a fixed characteristic. The only way to insure that instruments are and remain accurate is by initial and subsequent periodic checking. The successive steps involved in maintaining the instruments and standards necessary for checking test and service instruments ultimately refer all electrical measurements made in the United States to the standards of voltage, resistance, etc., maintained at the National Bureau of Standards in Washington, D. C.

Electrical Units and Standards. The name and size of the electrical units was changed on January 1, 1948, when the International Units previously used were replaced by the Absolute Units. Although this change will have no appreciable effect on most electrical measurements, it is of concern in connection with accurate measurements and the checking of high-accuracy instruments. The equivalent values of the

TABLE III

Equivalent of 1 Internat'l Unit Expressed in Corresponding Abs. Unit	*Unit*	*Equivalent of 1 Abs. Unit Expressed in Corresponding International Unit*
1.000495	Ohm	0.999505
1.000330	Volt	0.999670
0.999835	Ampere	1.000165
0.999835	Coulomb	1.000165
1.000495	Farad	0.999505
1.000165	Watt	0.999835
1.000165	Joule	0.999835

Values given in International Units may be expressed in corresponding Absolute Units by multiplying by the appropriate factor in the left-hand column; those given in Absolute Units may be expressed in International Units by multiplying by the appropriate factor in the right-hand column.

International and Absolute Units in terms of each other are given in Table III. All measurements now normally will be made in absolute units, but care must be used in accurate work to make clear and certain which units are used.

Requirements for Checking Instruments. Adequate reference instruments and standards, trained personnel, steady a-c. and d-c. power supplies and suitable circuit controls permitting fine adjustment of values are essential. All instruments should be in good operating condition and without evidence of friction or sticking. The pointer should be carefully set on zero and the moving element known to be balanced before attempting to check an instrument.

Suggested standards for checking various instruments are listed in Table IV.

TABLE IV—STANDARDS FOR CHECKING ELECTRICAL INSTRUMENTS and METERS

Instrument to be Checked			*Standard Instrument*	
Nominal Percent Accuracy	*Type or Kind*	*Checked on*	*Type or Kind*	*Minimum Percent Accuracy*
3 to 5+	D-c. Vacuum-tube Vm.	D.C.	Perm.-mag. Moving-coil	1
	A-c. Vacuum-tube Vm. (a), Rectifier (a)	A.C.	Electrodynamometer, Moving-iron or Thermocouple	
1.5 to 2	Perm.-Mag. Moving-coil	D.C.	Perm.-mag. Moving-coil	0.5
	Electrodynamometer, Electrostatic (g), Moving-iron, Thermocouple or Rectifier (a)	A.C.	Electrodynamometer, Thermocouple or Moving-iron	
0.75 to 1	Perm.-mag. Moving-coil	D.C.	Perm.-mag. Moving-coil	0.2 or 0.25
	Electrodynamometer, Electrostatic (g), Thermocouple or Moving-iron	A.C.	Electrodynamometer	
0.5	Perm.-mag. Moving-coil	D.C.	Perm.-mag. Moving-coil (b)	0.1
	Electrodynamometer, Thermocouple or Moving-iron	A.C.	Electrodynamometer	
0.2 to 0.3	Perm.-mag. Moving-coil, Electrodynamometer (c) or Moving-iron (c)	D.C.	Deflection Potentiometer (b, h)	0.05 to 0.1
			Null Potentiometer (h)	0.02 to 0.06
0.1	Perm.-mag. Moving-coil or Electrodynamometer (c)	D.C.	Null Potentiometer (h)	0.02 to 0.06
	Current Transformers	A.C.	Std. Current Trans. and Silsbee C. T. Test Set	
High	Std. Current Transformer	A.C.	Primary C. T. Testing Apparatus (d)	
	Potential Transformers	A.C.	Std. Pot. Trans. and Pot. Trans. Test Set.	
High	Std. Potential Transformers	A.C.	Primary Pot. Trans. Testing Apparatus (d)	
	Watthour Meters	A.C.	Rotating Standard (e)	
	Watthour Meter or Rotating Standard	A.C. or D.C.	Wattmeter (f)	(Wm) 0.25

(a) These instruments subject to large wave form errors so must be checked on sine wave alternating current. Wave form for checking all a-c. instruments should be sine wave.

(b) It usually is unnecessary to have both 0.1 percent laboratory standard d-c. instruments and deflection potentiometers. The deflection potentiometer is to be preferred for general use.

(c) The average of direct and reversed polarity readings should be used when checking these instruments on direct current.

(d) Primary apparatus for testing standard current and potential transformers available only at the National Bureau of Standards and possibly a few other laboratories.

(e) Device also required for starting standard at beginning and stopping standard at end of test interval.

(f) Precision timing device also required.

(g) Potential transformer also required for kilovolt ranges.

(h) The checking of potentiometers involves the high precision comparison and measurement of resistance and cannot be covered here, nor can the checking of standard cells. These checks can be made in a few adequately equipped laboratories or at the National Bureau of Standards.

Instrument potential circuits are connected in parallel and current circuits in series for calibration. A low-voltage current circuit usually is preferable in order to minimize power requirements. The current circuit may be, and sometimes should be, isolated from the potential circuit.

REGULATORS

Regulators maintain a voltage or current practically constant under all load and circuit conditions within their range of control. Voltage stabilizers maintain constant effective (rms) output voltage within about ±1 percent or less to a fixed load for a specified range of input voltage, usually about ±15 percent. Fig. 17 shows a typical stabilizer circuit. They will not maintain constant output voltage with change in load or output power factor, the voltage change amounting to 1 to 3 percent at unity and 5 percent or more at 0.8 power factor. The output voltage is frequency sensitive, changing 1 to 2 percent for each percent change in frequency. A disadvantage for some applications is the 5 to 20 percent harmonic content of the output voltage. Several seconds may be required to stabilize the output after a sudden change in load or input voltage.

Electronic voltage stabilizers and regulators will maintain output voltage constant after an initial warm-up period of about 30 minutes within ±1 percent or less for about ±15 percent change in input voltage with change in both load and output power factor, but not always over the entire nameplate range. Stabilization may be better than the regulation. Harmonic content added usually is less than 3 percent. Some recover from a change in load or input voltage within 0.25 second, others may require almost a second. Tube replacement may increase the output voltage variation or make readjustments necessary.

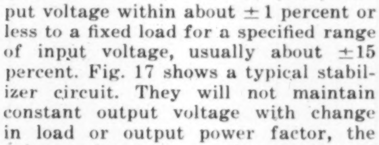


Fig. 17. Schematic circuit of typical voltage stabilizer.

Induction regulators are a special type of autotransformer with one stationary and one rotatable winding arranged so the latter can be held in any position. The primary portion of the winding is connected across the line and the secondary in series with the load. In the single-phase regulator, the direction (add or subtract) and magnitude of the secondary voltage are determined by the rotor position. In the three-phase type, the secondary voltage is constant but the angle at which it adds to the input voltage is varied to control the output voltage, thus producing a phase shift of the output voltage as well as a change in magnitude. Step-voltage regulators consist of a fixed-coil autotransformer with taps on the secondary to change the output voltage in fixed steps, with a motor-driven tap changer arranged so the taps can be changed under load. Table V gives some data on these regulators.

Constant-current regulators are of two types. Constant-current transformers are special shell-type transformers with one fixed coil, the other being movable in a vertical direction and partially counterweighted so the repulsion force between the coils at the desired secondary current value provides the additional force necessary to maintain equilibrium. The secondary current is maintained constant for values of load impedance below the maximum specified for a given regulator, but the minimum sustained load usually is not less than about 50 percent of this value. Static constant-current regulators are a resonant network consisting of two inductors and two

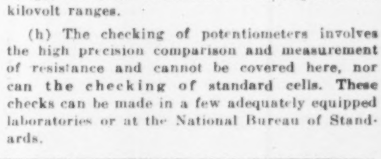


Fig 18. Static constant-current regulator.

TABLE V—CIRCUIT VOLTAGE REGULATORS

Type	*Application*	*Operated by*	*Control*	*Number of steps*	*Size of Steps %*	*Range of Control %*	*Operating Voltage*
Single-phase Induction	**Individual loads or circuits**	**Hand**	**Hand**	Infinite	**Stepless**	±50	110-220
		Motor	Voltage Relay	Infinite	**Stepless**	±10	110-440
Single- or Three-phase Induction	Distribution Circuits and Feeders	**Motor**	Voltage Relay	Infinite	**Stepless**	±10	6900 or lower
Booster Step-voltage	Small capacity feeders and rural lines			One fixed, 1 or 2 automatic	2.5	10	
Branch Feeder	Branch feeders	**Motor**	Voltage Relay	4 8	2.5 1.25	10	2400-13800
Single- or Three phase Step-voltage	Transmission lines and high capacity distribution ckts.	**Motor**	Voltage Relay	16 32	1.25 0.625	±10	2400-69000

TABLE VI—GENERATOR VOLTAGE REGULATORS

Type	*Application*	*Operating Element*	*Control Elements*	*Operation*
Vibrating (Tirrill)	A.C. or D.C	Vibrating relay, either a-c or d-c	Voltage relay	Section of field resistance short circuited by relay contacts. Voltage fluctuates slightly. Operates continuously.
Direct Acting Rheostatic	A.C. or D.C	Control element and spring in opposition	Voltage relay or torque motor	Resistance element either carbon plates or tapped resistance. Operates directly in generator or exciter field. No voltage fluctuation. Operates only when voltage correction necessary.
Indirect Acting Rheostatic	A.C.	Motor for normal response, relays for quick response	Voltage relay	Varies resistance in generator or exciter field by motor and relays. Has both normal and quick-response features. Holds voltage steady and operates only when correction is necessary.
Network	A.C.	Amplifier	Impedance Network	Uses one linear and one nonlinear impedance. Difference current reverses and is zero at normal voltage and controls amplifier whose output supplies generator or exciter field.
Electronic	A.C.	Thyratrons	Diff. between ref. and output voltage	May supply excitation to generator field, exciter field or electronic exciter.

capacitors arranged in a bridge circuit with input and output terminals as shown in Fig. 18. The impedances of the inductors and capacitors are equal at the operating frequency. The regulator supplies constant current to a variable high power-factor load between specified limits if the input voltage is constant.

There are several types of regulators for maintaining constant terminal voltage of a-c. and d-c. generators, as listed in Table VI. All are, in effect, amplifiers as a small change in voltage is amplified into the large change in field current necessary to restore the voltage to normal within the tolerance permitted.

ACKNOWLEDGEMENTS

Appreciation is expressed for the cooperation of several instrument manufacturers and others who have furnished material incorporated in this chapter or assisted in its preparation. Mr. M. F. Behar has been particularly helpful, also Dr. F. K. Harris and Mr. F. D. Weaver of the National Bureau of Standards and Mr. R. E. Wendt of the University of Illinois. Test data on voltage stabilizers were made available by Mr. T. W. Cushing of the National Bureau of Standards.

PICTURE CREDITS

Weston Electrical Instrument Corp.: Figs. 1, 3, 4, 5, 6, 7, 12.

General Electric Co.: Figs. 2, 8, 9, 10, 11.

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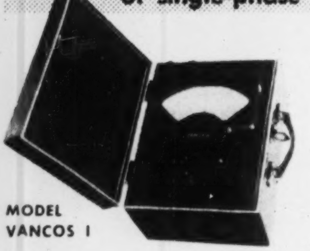

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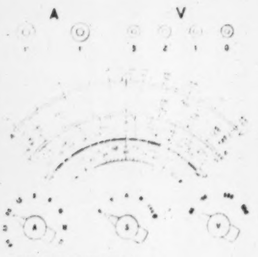

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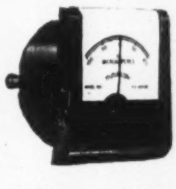
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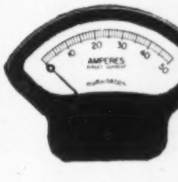

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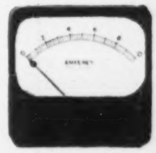
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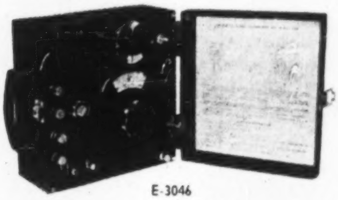
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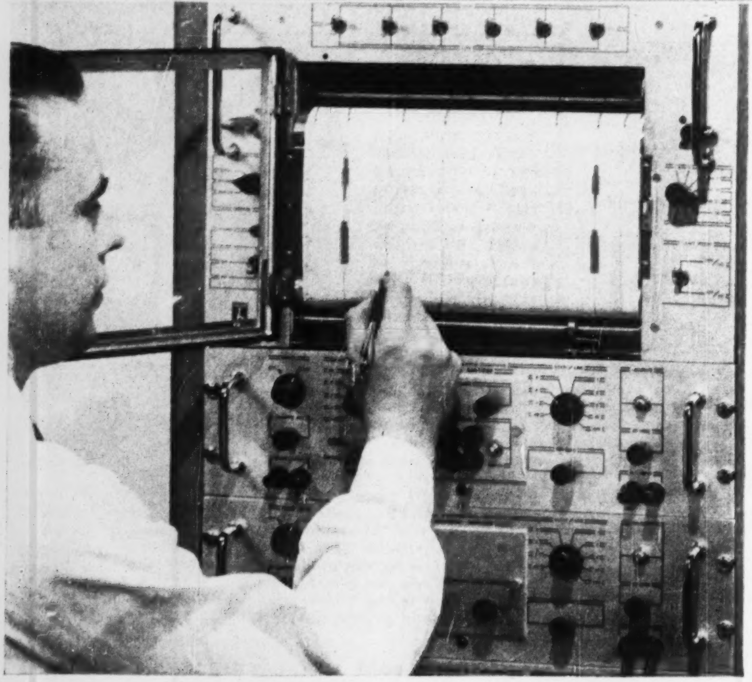

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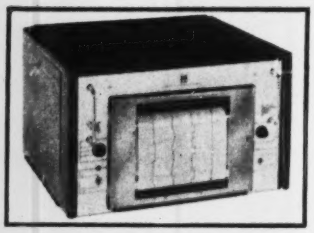

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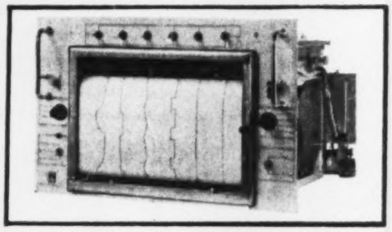

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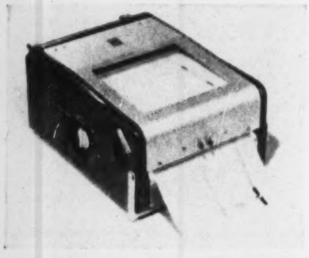

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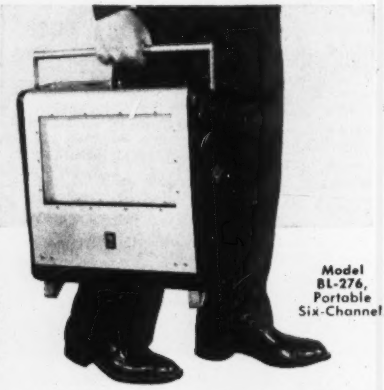

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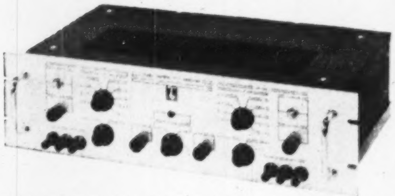
Amplifiers



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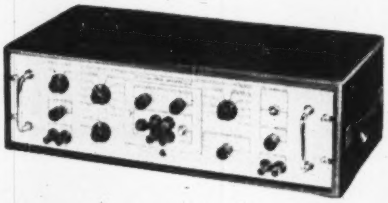

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Above illustration shows Portable Case for use with new Brush Amplifiers. Equipped with handles for easy carrying. Ideal for bench operation where units may be stacked for economy of space.

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BRUSH INSTRUMENTS

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BL-202	Double Channel Direct Inking Oscillograph
BL-206	Six-Channel Direct Inking Oscillograph
BL-208	Six-Channel Electric Writing Oscillograph
BL-213	Welding Analyzer
BL-221	Single Channel Combination Oscillograph
BL-222	Double Channel Combination Oscillograph
BL-254	Four-Channel Direct Inking Oscillograph
BL-256	Six-Channel Oscillograph
BL-264	Four-Channel Combination Oscillograph
BL-266	Six-Channel Combination Oscillograph
BL-274	Portable Four-Channel Ink or Electric Writing Oscillograph
BL-276	Portable Six-Channel Ink or Electric Writing Oscillograph
BL-312	Universal* Bridge Switch
BL-314A	Textile Uniformity Analyzer*
****BL-320**	Universal* Strain Analyzer
BL-520	Universal* Amplifier
BL-530	Dual Channel D.C. Amplifier
BL-905	A.C. Amplifier, High Gain
****BL-928**	D.C. Amplifier, Dual Channel, Low Gain
****BL-932**	D.C. Amplifier, Single Channel, High Gain
BL-933	Chart Takeup Drive, for use with BL-201, BL-202, BL-221, BL-222
BL-954	A.C. Pre-Amplifier, High Gain
BL-502	Transient Recorder
BL-301	Vibration Pickup, inertia type
DP-1	Vibration Pickup, displacement type
DP-1H	Heartbeat Pickup, similar to DP-1, with flat diaphragm

ELECTRO-ACOUSTICAL INSTRUMENTS

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BL-1502	Deviation Test Bridge
BL-1604	Integration Network for Vibration Pickup BL-4304
BL-4304	Vibration Pickup
BL-2002	Heterodyne Voltmeter
BL-2105	Frequency Analyzer
BL-2109	Audio Frequency Spectrometer
BL-2304	Level Recorder
BL-2423	Megohmmeter and D.C. Voltmeter
BL-3423	Megohmmeter High Tension Accessory
BL-4002	Standing Wave Apparatus
BL-4111	Condenser Microphone
BL-4120	Reciprocity Calibration Apparatus and Accessory
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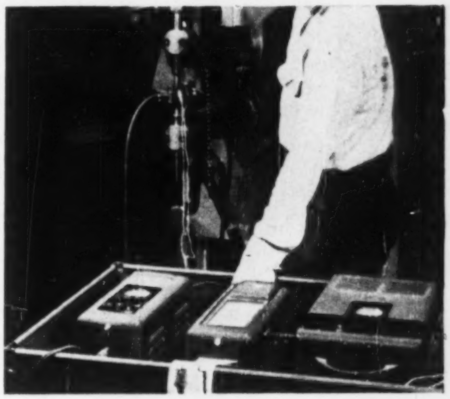
**Amplifier available in portable or rack mounting



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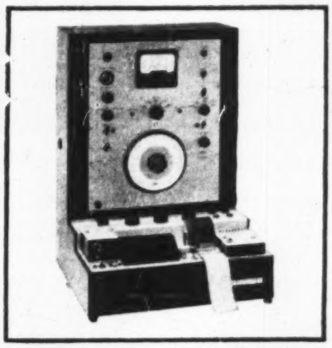

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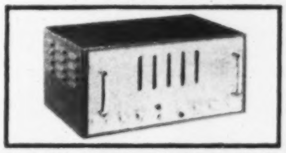

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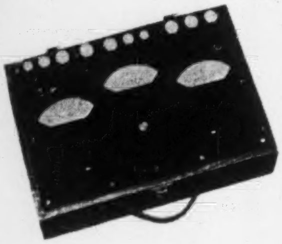

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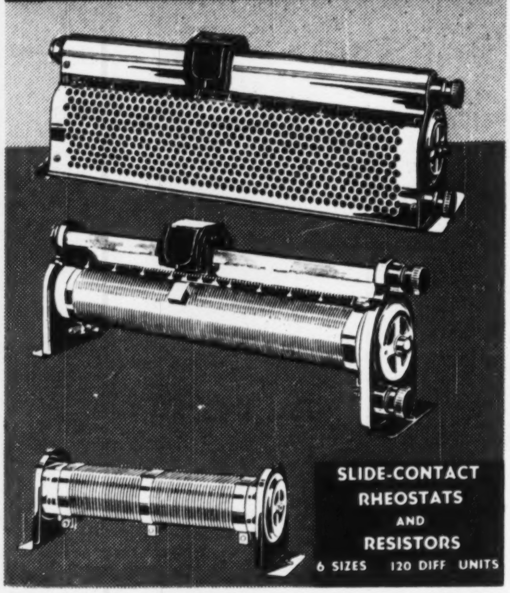

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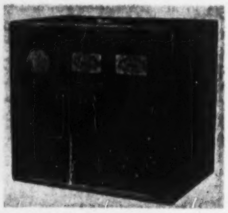

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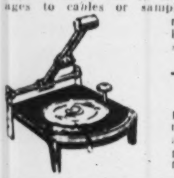

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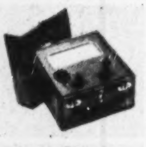

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CHAPTER XI

ELECTRONIC TEST INSTRUMENTS

By M. H. ARONSON

BASIC test instruments usually found in any shop where electronic equipment is serviced include the (1) vacuum-tube voltmeter (VTVM), a-c. and d-c., (2) signal generator, (3) oscilloscope, and (4) tube tester. These four basic test instruments will be described in detail in this chapter.

In addition, there may be found many other test instruments designed for specific uses—high voltage a-c. and d-c. test equipment, magnetic-field equipment, bridges and *Q* indicators, decade resistors, decade capacitors, decade inductors, frequency meters, harmonic analyzers, panoramic adapters, special resistance meters, pulse instruments, voltage-standing-wave-ratio (VSWR) indicators, attenuators, phase meters, electrometers, power supplies, cathode followers, impedance meters, computers, etc., etc.

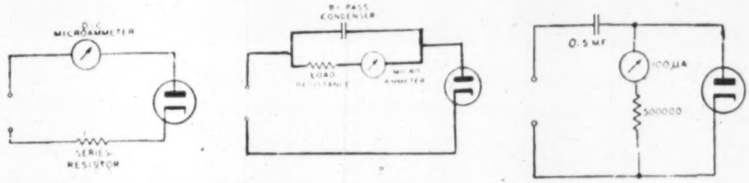

Fig. 1. Basic diode VTVM circuits for a-c. measurement (see Types I, II, III, table 1).

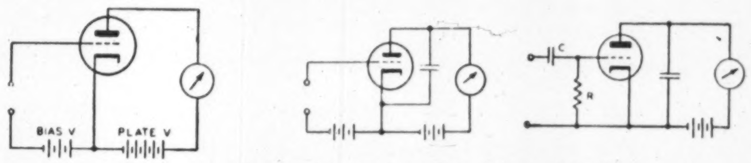

Fig. 2. Basic triode VTVM circuits (see Types IV, V, VI, table 1).

1. Vacuum-Tube Voltmeters

The term "vacuum-tube voltmeter" refers to an instrument which uses vacuum tubes to measure voltage. (Many d-c. VTVM's also measure current and resistance.) A simple VTVM, consisting of but one diode and an indicator, may have only one voltage range; a complex VTVM may have a-c. and d-c. voltage ranges from 0.0001 to 1000 volts, plus a wide-range ohmmeter, plus a standard cell for precision calibration, plus distended scales for measuring large voltages to an accuracy of 0.01 percent. Within these extremes are many commercial types and models.

Table 1 lists the basic VTVM circuits, which are shown in Figs. 1 to 6. Diodes and triodes are the basic tubes used (variable-mu pentodes are used in logarithmic-scale a-c. VTVM's, all are Type IX, the amplifier-rectifier type).

Basic use of diodes is to rectify an a-c. signal so that it can be indicated and measured by a d-c. permanent-magnet moving-coil indicator. (This type of indicator is standard in almost all VTVM's.) There are three basic diode a-c. VTVM's, as shown in Table 1 and Fig. 1. These are (1) series-resistor type, (2) peak-reading series type, and (3) peak-reading shunt type. The series-resistor type has limited frequency response because distributed capacitance bypasses r-f. current around the high-valued resistor, making the reading higher as frequency is increased. The higher the value of R, the more limited is the frequency response. In Type I, a 100,000-ohm resistor and a 100-microampere movement would give full-scale deflection of about 23 volts rms.

The two peak-reading diode VTVM's are used more commonly. As the load resistor (R) is not in series with both the source and the diode, the frequency response is improved. The input resistance is made up of R and the biased diode, and is approximately equal to R/2. As in all peak-reading voltmeters, waveform error appears if the waveform is not sinusoidal. The sensitivity depends on R and the indicator; a 1-megohm resistor and a 100-microampere movement produces a 100-volt peak range ($E = IR$), which is about 70 volts rms.

Wherever diodes are used, the *contact potential* must be considered. This is the potential developed on the plate of a diode even when no signal is applied. Its value depends on the resistance in series with the diode and is about 0.5 volt with 20,000 ohms in series with the diode; about 1 volt with megohms. This contact potential can be balanced out by a second diode or by a battery, but the calibration will not be linear at low signal levels (less than a few volts) because the diode resistance is high at low voltages.

Crystal diodes or germanium or silicon often are used instead of vacuum-tube diodes. These do not have contact potential and do have superior high-frequency operation owing to their low shunt capacitance.

Triode VTVM's.

Types IV, V, and VI in Table 1 are the basic triode VTVM's (Fig. 2). The basic triode d-c. VTVM (Type IV) is often used as the final stage in more complicated VTVM's—with bucking and balancing circuits. These circuits remove the basic limitation of this type—that is, the poor low-signal linearity caused by the nonlinear tube characteristic (plate current vs. grid voltage)—by permitting the tube to operate at a linear portion of its curve. Fig. 3 shows a basic balanced VTVM of the d-c. type: one tube is the measuring tube whose plate current is controlled by the applied grid signal; the other tube is a balancing tube that permits the indicator to start at zero even though plate current is flowing in both tubes. This balanced-type circuit, preceded by a rectifier-amplifier combination that gives both a-c. and d-c. response at high sensitivity, is a common type of general-purpose VTVM (Type VIII in Table 1).

Inverted-triode VTVM's (Fig. 4) are used for high-voltage measurement. Special high-voltage probes with voltage-dividing networks are available also as an auxiliary for conventional low-range VTVM's of Types VIII and IX.

Types VIII and IX in Table 1 are the most common VTVM instruments available commercially. The top circuit in Fig. 5 shows a rectifier-amplifier

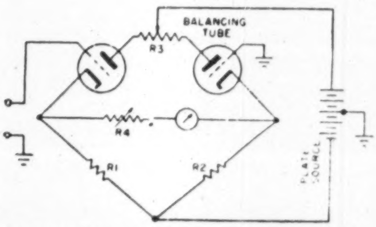

Fig. 3. Basic balanced d-c. VTVM circuit, in which measuring tube can be used on linear portion of its characteristic.

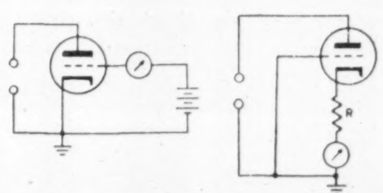

Fig. 4. Inverted-triode-type VTVM's for high-voltage measurement (see Type VII, table 1).

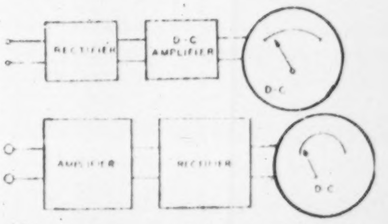

Fig. 5. Basic general-purpose VTVM's (see Types VIII and IX, table 1).

TABLE 1.—BASIC TYPES AND CHARACTERISTICS OF VTVM CIRCUITS.

Type	*Principle*	*Advantages*	*Limitations*
I. Diode AC VTVM; series-resistor type (Fig. 1).	Average rectified current is proportional to applied AC signal. Load resistor increases input resistance and linearity.	1. Simplicity. 2. Can be used up to low radio frequencies.	1. Limited frequency response. 2. Low input resistance (use of high load resistor causes reduced sensitivity). 3. Not used much.
II. Diode AC VTVM; peak-reading series type (Fig. 1).	Capacitor charges and biases diode so that only a small surge of current flows on positive peaks. RC is chosen to be large compared to time of 1 cycle at lowest frequency to be used. Sensitivity depends on R and indicator movement.	1. Simplicity. 2. Frequency error is low from low frequencies (established by RC value) to high ratio frequencies. 3. Commonly used as second detector in superhet receivers. 4. Input resistance is approximately R/2.	1. Calibration may not be the same at all frequencies. 2. Sensitivity goes down as value of R increases. 3. Meter current must flow through source. 4. Diode contact potential becomes troublesome for small signals (less than 1 volt). 5. As it is peak reading, waveform error exists if peaks are not uniform.
III. Diode AC VTVM; peak-reading shunt type (Fig. 1).	Same as II, except source is isolated from measuring circuit by coupling capacitor. Figure shows 0-50 volt range, as established by 0.5-meg R and 100-ua. movement.	Same as II, plus 5. No DC path required through source.	Same as II.
IV. Triode DC VTVM; simple type (Fig. 2).	Tube is biased to cutoff. Signal causes proportional plate current. Balancing circuit can be used to buck out zero-signal plate current to increase low-signal linearity (Fig. 3).	1. High input resistance (hundreds or thousands of megohms). 2. Good linearity (for large signals, as established by tube characteristics). 3. High sensitivity.	1. Poor low-signal linearity. (unless bucking circuit is used). 2. Limited range (as established by tube characteristics).
V. Triode AC VTVM; plate-rectification (or plate-detection) type. Also self-bias or reflex type (Fig. 2).	Tube is biased either to cutoff or below or above. First two give ½-wave-rectification operation; third gives full-wave operation. (Full-wave type has least waveform error). Average plate current is proportional to applied AC signal. Bias can be obtained from cathode resistor (this type is known as self-bias, or reflex, type).	1. High input resistance. 2. Useful to high radio frequencies (above 30 Mc.). 3. Higher sensitivity than diode types. 4. Self-bias type can be used to 50 Mc. with acorn tubes.	1. Curved tube characteristic causes square-law response to weak signals. 2. Self-bias type has less sensitivity (but more linearity) than bias-battery type. 3. Can have waveform error.
VI. Triode AC VTVM; grid-rectification type (Fig. 2).	On positive signal swings, the grid draws electrons from cathode, charging capacitor C and biasing tube. Plate current depends on bias and hence on signal.	1. High sensitivity for weak signals (0.1 to 1.0 volt).	1. Reduced input resistance because grid draws current. 2. High plate current at zero signal. 3. Square-law response for weak signals.
VII. Inverted triode (Fig. 4).	High-voltage signal is applied to plate. Grid may have positive bias, or self-bias may be obtained from cathode resistor. Indicator in grid or cathode circuit shows current proportional to applied voltage. Transmitter-type tubes usually used.	1. High-voltage measurement (up to 30,000 volts). 2. High input resistance (up to 10^7 megohms).	1. Upper frequency limit in low-megacycle range because of tube capacitance. 2. Low sensitivity.
VIII. Rectifier-amplifier-type AC VTVM's (Fig. 5).	Rectifier followed by DC VTVM. Rectifier circuit can be mounted in probe for high-frequency work. Rectifier usually is crystal or double diode (one of which is rectifier, other is used to balance out diode contact potential).	1. Wide range of frequencies (up to several hundred Mc.). 2. Most popular general-purpose type.	1. Sensitivity limited to about 1 volt full scale because of poor linearity of rectifier to weak signals. 2. Low-frequency limit is usually 60 cps.
IX. Amplifier-rectifier AC VTVM's (Fig. 6).	AC amplifier followed by rectifier and DC VTVM. AC amplifier is broadband stabilized amplifier for precision measurement. Wide-range decibel (log) scales obtained by use of shaped pole pieces in indicator movement or by use of logarithmic characteristics of variable-mu tubes.	1. High sensitivity. 2. Many variations available for wide-range work, usually with logarithmic decibel scales. 3. Most popular for audio-frequency work.	1. Does not have the frequency response of rectifier-amplifier type. 2. Low-frequency limit is usually 10-20 cps. 3. High-frequency limit is usually 2-4 Mc.
X. Slideback VTVM; diode type (Fig. 8).	Uses null principle. An adjustable voltage is inserted in series with the unknown voltage, and is varied until meter indicates null (or some predetermined value). Either series-type or shunt-type circuit can be used (as in I and III above).	1. Can measure positive peak voltage, negative peak voltage, or DC level of AC signal (trough voltage)—by reversing polarity of slideback voltage and diode. 2. Useful as modulation meter. 3. Useful at very low frequencies (1 cps.), where conventional VTVM's have error. 4. Useful for pulses.	1. Accuracy decreases for signals less than a few volts (unless calibration is made). 2. As it is a peak-reading VTVM, waveform error can exist. 3. Rectifier characteristic at weak signals is poor, hence use is recommended for voltages above a few volts. 4. Calibration and correction curves required for accuracy better than a few percent.
XI. Slideback VTVM; triode type (Fig. 8).	Same as X, except triode is used instead of diode.	1. Measures positive peaks only (also DC signals, but not recommended). 2. Higher sensitivity than X. 3. Has less error for weak signals than X. 4. High input resistance (higher than type V above because grid is excited only on positive peaks). 5. Useful at very low frequencies.	1. Subject to same waveform errors as all peak-reading VTVM's. 2. Useful only on positive peaks. 3. Meter must be protected when unknown signal is applied and slideback voltage is not applied.

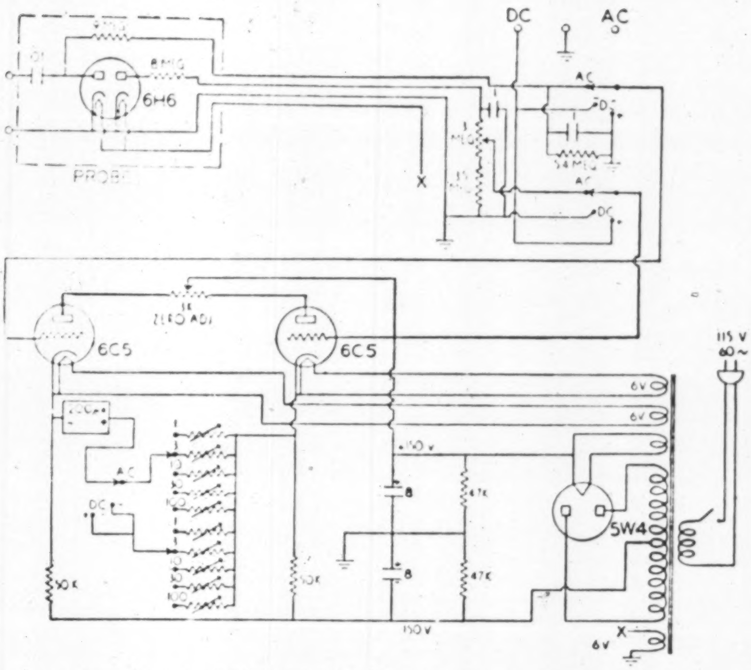
DC
AC
6H6
8 MEG
PROBE
X
AC
DC
1 MEG
54 MEG
6C5
6C5
1K
ZERO ADJ
115 V
60~
6V
6V
150 V
8
47K
5W4
50K
150V
6V
X
30K

Fig. 6. Typical VTVM circuit (with probe rectifier for a-c. measurements).

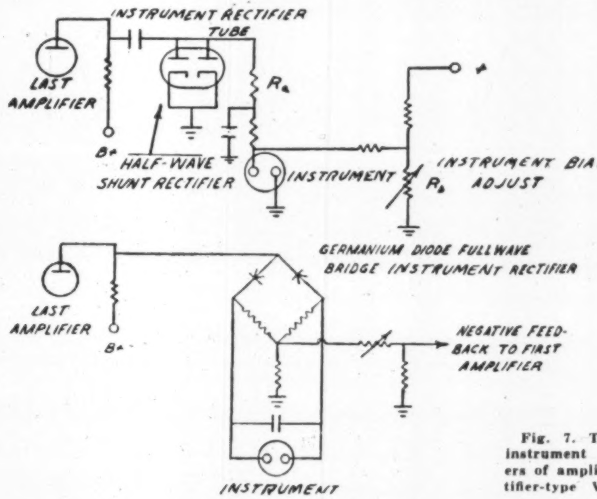
INSTRUMENT RECTIFIER TUBE
LAST AMPLIFIER
B+
HALF-WAVE SHUNT RECTIFIER
R_a
INSTRUMENT
INSTRUMENT BIAS ADJUST
R_b
GERMANIUM DIODE FULLWAVE BRIDGE INSTRUMENT RECTIFIER
LAST AMPLIFIER
B+
NEGATIVE FEEDBACK TO FIRST AMPLIFIER
INSTRUMENT

Fig. 7. Typical instrument rectifiers of amplifier-rectifier-type VTVM's.

type. The rectifier is usually an auxiliary so that the VTVM is essentially a d-c. VTVM. The basic shortcoming of this type of VTVM is limited sensitivity caused in part by poor linearity of rectifiers to weak signals.

The amplifier-rectifier-type (Fig. 5, bottom) overcomes the sensitivity limitation of the rectifier-amplifier type, but at the expense of frequency response because the rectifier in the latter type is usually a high-frequency unit in a special probe tip. (Fig. 6). The basic types of rectifier circuits used in amplifier-rectifier-type VTVM's are shown in Fig. 7.

The features desired in a VTVM are (1) high input impedance to both a-c. and d-c. signals, (2) high sensitivity and several ranges, (3) wide frequency response, (4) protection against overloads, and (5) scales for current and resistance measurement. As shown in Table 1, no one VTVM has all these characteristics. However, one Type VIII (rectifier-amplifier type) plus one Type IX (amplifier-rectifier type) will meet most general-purpose applications.

Note that the Type IX (amplifier-rectifier) is available with wide-range decibel (logarithmic) scales. This is done by use of special indicating-instrument movements with shaped polepieces to give logarithmic response, or by feedback in an amplifier which uses variable-mu tubes to give the logarithmic response. The advantages of logarithmic response are (1) response to signals of widely different amplitude and (2) equal percent-accuracy of measurement in all regions of the scale.

Special VTVM's are available for pulse measurement. Others have distended scales (a small portion of the scale is extended over the full scale) permitting measurement of millivoltages at any voltage level.

Slide-back VTVM's

Slide-back vacuum-tube voltmeters (Fig. 8) use the null principle of bucking out the applied unknown signal with an accurately calibrated slide-back voltage. All the basic VTVM circuits can be used, with their attendant advantages and disadvantages. The slide-back feature permits measurement of very-low-frequency signals (fractions of a cycle), of peaks, troughs, percentage modulation, etc., as in Table 1.

Uses

Vacuum-tube voltmeters have many uses in addition to their primary function of measuring signal amplitude. These uses include (1) measurement of circuit impedance, (2) measurement of internal impedance of a signal generator, (3) null detection in bridge circuit, (4) voltage amplification, (5) measurement of alternating currents, and (6) measurement of parallel-resonant circuit impedance.

Measurement of Circuit Impedance by 6-db.-drop Method. Use apparatus as shown in Fig. 9, using an oscillator of *known* internal impedance. With the decade resistor disconnected, adjust the oscillator level to give a convenient reading on the VTVM. Connect the resistance decade and adjust its value (R) until the VTVM reads 6 db., or 50* percent, of its initial value. At this reading the generator impedance (Z_G)

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*Note: 6 db. is about 50-percent change in voltage; 3 db. is about 50-percent change in power.

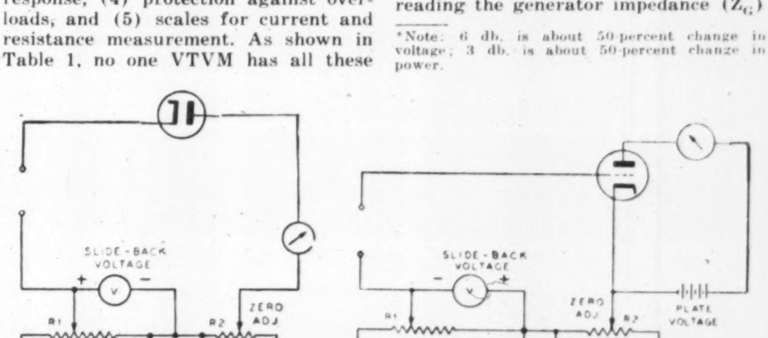
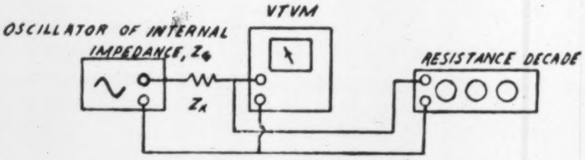

SLIDE-BACK VOLTAGE
+
V
−
R1
R2
ZERO ADJ
Y
X
+
−
SLIDE-BACK VOLTAGE
−
+
V
R1
ZERO ADJ
R2
E2
E1
PLATE VOLTAGE

Fig. 8. Basic slide-back VTVM circuits (see Types X and XI, table 1).

Fig. 9. Set-up for measuring circuit impedance or oscillator impedance with an a-c. VTVM.



plus the unknown impedance (Z_X) equals the circuit impedance R:

$$R = Z_G + Z_X$$

Resistance R must be resistive at the test frequency. The oscillator output must be sinoidal.

Measurement of Generator Impedance. Use the 6-db.-drop technique also for measurement of the internal impedance (R) of a signal generator. Connect apparatus as shown in Fig. 9 with the resistance decade disconnected. Adjust generator until a convenient reading is obtained on the VTVM. Connect resistance decade and adjust it until the VTVM reads 50 percent of voltage, or 6-db. drop. R then equals Z_X.

Null Detection. The VTVM can be used as a null detector in a bridge circuit. When an a-c. VTVM is used in an a-c. bridge, the bridge should be operating at frequencies within the frequency-response range of the VTVM.

Voltage Amplification. The VTVM may be used as a voltage amplifier for oscilloscope input magnification. Two VTVM's may be used in series where noise levels are relatively low and absolute accuracy is not important.

Current Measurement. The VTVM can be used as a multi-range a-c. ammeter with use of precision noninductive shunts, or even with resistance wire (Fig. 10). This is often useful when a thermal-type meter is not available, particularly since rectifier-type multi-test sets do not have a-c. ampere or milliampere ranges. Caution must be used to insure that the voltage drop is actually measured across the precision resistor and not across any portion of the connecting leads, clips or attachments; good contact must be obtained.

Resonant-circuit Impedance. The VTVM can be used to measure parallel-resonant circuit impedances and, consequently, the approximate Q of tank circuits. A set-up as in Fig. 11 is used. The VTVM must be insulated from ground; a "push-to-test" switch should be included to protect personnel.

The circuit anti-resonant impedance is determined by comparison of the VTVM indication of the voltage across the 100-ohm resistor against the indication across the tank circuit. The VTVM must have high input resistance and low input capacitance.

Maintenance and Calibration

The manufacturer's literature usually presents detailed maintenance techniques. In order of performance, the routine service technique includes (1) check and renewal of tubes, (2) physical check, (3) check of absolute calibration, (4) check of cross-scale tracking, (5) check and compensation for frequency response, and (6) run-in and final check.

2. SIGNAL GENERATORS

Signal generators are oscillators that produce signals for testing, adjusting, or calibrating electronic circuits.

There are two basic types of signal generators,—frequency standards and test oscillators. The former provides a relatively weak signal of high frequency-stability and low harmonic-content; the latter provides a stronger signal of less stability. The signals usually are adjustable both in frequency and amplitude for maximum utility; ranges of adjustment of both frequency and amplitude are important characteristics of signal generators. High-quality generators do not change signal amplitude with frequency change, and vice-versa.

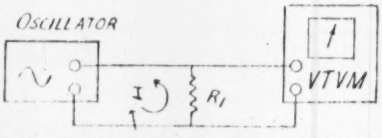


Fig. 10. Set-up for use of a-c. VTVM as ammeter or microammeter. I is current to be measured; R must be non-inductive.

Features of Test Oscillators

The test oscillator delivers a signal either pure, tone-modulated, or frequency-modulated, for testing and adjusting electronic circuits. Accuracy of output frequency is not as important as is adequate and adjustable signal strength (amplitude). This is because the test signal may be applied to either high-gain or low-gain circuits; the former require only small signals, the latter require large signals. In operation it is important that the output test signal remain constant when the signal is coupled into various parts of a circuit for test or analysis. Many test oscillators have an output meter so that the output can be measured and maintained constant by manual adjustment.

Most test oscillators provide outputs at various impedances—the most common being, 50, 72, 300, 500, and 600 ohms. This is done to provide maximum power transfer to the circuit under test, to minimize reflections and standing waves, and to make comparisons of voltage measurements at different impedances.

Secondary standards and high-stability test oscillators use regulated power supplies. Line-voltage regulation also should be used when portable a-c. generators or fluctuating line-voltages are used. It is important to remember that oscillators do not reach maximum stability until they are in operation for a time sufficient for the circuit to reach a stable temperature.

WWV Standard-frequency Transmissions

Station WWV, the National Bureau of Standards, transmits standard radio frequencies that are useful for checking frequencies and testing circuits and other oscillators. The schedule of WWV transmissions is shown in Table 2.

Table 2—SCHEDULE OF WWV SERVICES

Carrier Frequency, Mc.	*Time of Broadcast*	*Power Output, kw.*	*Modulating Frequencies, cps.*
2.5	Continuously	0.7	1 and 440
5.0	ditto	8.0	ditto
10.0	ditto	9.0	1,440 and 4000
15.0	ditto	9.0	ditto
20.0	ditto	8.5*	ditto
25.0	ditto	0.1	ditto
30.0	ditto	0.1	1 and 440
35.0	ditto	0.1	1

* 0.1 kw. for first 4 work days after 1st Sunday of each month.

Each carrier frequency and each audio frequency is accurate to better than 1 part in 50,000,000. Each interval of 1 second is accurate to 1 microsecond. Station letters WWV and voice announcements are given 1 minute before the hour and half hour.

Circuits

Many basic oscillator circuits are used—phase-shift, Wien-bridge, and beat-frequency oscillators are used as test oscillators at low frequencies (from a fraction of a cycle to ultrasonic frequencies); tuning-fork oscillators are used as audio-frequency secondary standards. Electron-coupled, dynatron, and transitron oscillators are used from very low to high radio frequencies; crystal-controlled and electron-coupled oscillators are used as secondary frequency standards at these frequencies. The ultraudion, Klystron, and magnetron oscillators are used at radio frequencies in the VHF, UHF, and SHF bands (see Table 3 for the decade classification of radio waves). The Klystron is the more stable continuous-wave (c-w.) oscillator and is used most often at UHF and SHF frequencies.

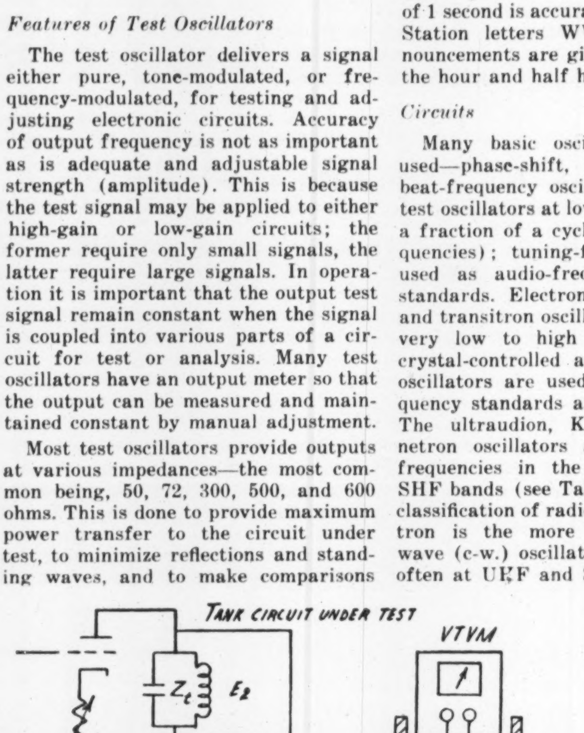


Fig. 11. Set-up for using an a-c. VTVM to measure resonant-circuit impedance and approximate Q of tank circuit.

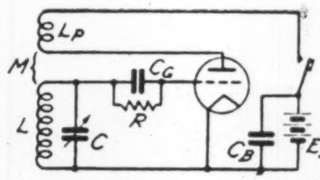


Fig. 12. Tickler-coil oscillator.

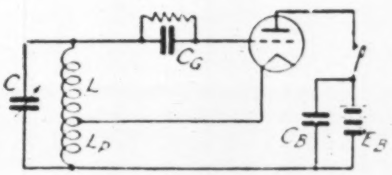


Fig. 13. Hartley oscillator.

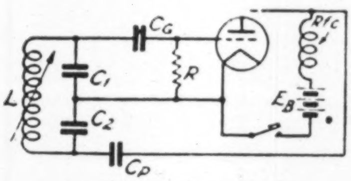


Fig. 14. Colpitts oscillator.

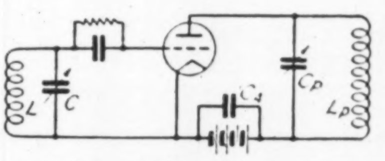


Fig. 15. Tuned-plate tuned-grid oscillator.

Tickler Coil

One of the basic oscillator circuits is the tickler-coil oscillator, shown in Fig. 12. The resonant tank is inductor L and capacitor C in parallel. As the natural resonant frequency of the tank is $1/(2\pi)(LC)^{1/2}$, the capacitor or inductor can be made variable so that the resonant frequency is adjustable. The capacitor usually is made variable. The C_G and R network provides grid-leak bias, which is used in almost all oscillators because it enables the oscillator to start oscillating easily and then provides stable bias.

If the R-C_G time constant is made large, the oscillator will oscillate for an instant and then block until the capacitor discharges through the resistor. This type of *blocking oscillator* is used widely for producing pulses.

When the oscillator is first turned on there is a surge of current that excites the tank. This signal is amplified by the amplifier. Tickler coil L_p is wound and placed so that a small amount of signal is inductively fed back into the tank; the coupling coefficient is represented by M. The feedback signal is of the proper polarity and amplitude to sustain a pure sinoidal oscillation.

The oscillator output can be fed to any desired circuit by either a connection to the tank or by another coil brought near the tank. This type oscillator is used widely in radio receivers as a *local oscillator* for heterodyning radio-frequency signals to a lower, or intermediate, frequency.

Hartley Oscillator

The Hartley oscillator (Fig. 13) is similar in principle and operation to the tickler-coil oscillator, except that one tapped inductor is used. A positive signal surge at the grid causes plate current to increase. The current flows up through L_p, causing the tap on L_p to become more positive than the bottom. This in turn induces a more positive signal at the top of L. As a positive signal at the grid results in a more positive feedback signal at the grid, oscillation is sustained.

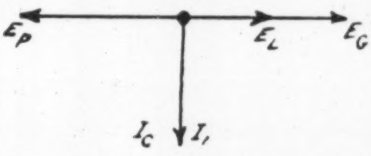


Fig. 16. Phase relations showing how the plate signal of a tuned-plate tuned-grid oscillator is shifted 180 degrees during feedback to the grid.

Colpitts Oscillator

The Colpitts oscillator (Fig. 14) is similar to the Hartley, except that a pair of capacitors, C_1 and C_2, replace the tapped coil. The circuit action is similar in all other respects because the capacitors produce an effective tap on the coil. The inductance usually is varied for tuning, although capacitors C_1 and C_2 can be ganged and varied for tuning. The radio-frequency choke (RFC) is used in all oscillators to block the oscillations from the power source.

Tuned-Plate Tuned-Grid Oscillator

The tuned-plate tuned-grid oscillator (Fig. 15) has a tuned circuit in both the grid and the plate circuits. The feedback from plate to grid occurs through the small interelectrode capacitance. As the plate signal is 180 degrees out of phase with the grid signal, there must be another 180-degree phase shift in the feedback signal in order to produce oscillation. This occurs because the tanks are tuned to a frequency that is slightly higher than the oscillation frequency. Thus the tank is more inductive than capacitive. When current is fed through a tiny capacitor to an inductor, the voltage developed across the inductor is shifted in phase by 180 degrees. This shift makes the feedback signal in phase with the grid signal, thus sustaining oscillation.

Fig. 16 illustrates the phase relations. E_G is the grid signal. This produces E_P, the plate signal. E_P produces I_C, the feedback current through the interelectrode capacitance. As the interelectrode capacitance is in series with the inductive tank, the current through the tank (I_L) is the same as I_C. However, a current through an inductor lags the voltage across the inductor by 90 degrees. Therefore I_L produces feedback signal E_L, which is in phase with E_G and thus sustains oscillation.

For this to occur, the grid tank must be inductive (tuned to a frequency higher than the resonant frequency) and the reactance of the feedback interelectrode capacitance must be higher than the reactance of the tank. As only the small interelectrode capacitance is used for feedback, both conditions are true and the circuit oscillates.

Ultraudion Oscillator

The ultraudion oscillator (Fig. 17) is used frequently at ultra-high frequencies. As the grid and plate are connected to opposite ends of the tank circuit, 180-degree phase inversion occurs because the opposite ends of a coil are always at opposite polarities—when one end goes positive, the other goes negative. However, this is true only when a point on the coil is grounded or kept at a fixed potential. This occurs in the ultraudion because the grid-cathode and plate-cathode capacitances act like the two capacitors in the Colpitts oscillator, effectively tapping and grounding a point on the coil. Capacitors C_2 and C_3 block the plate current from the tank, but pass r-f. oscillations with negligible reactance. Grid-leak bias is developed across resistor R_G.

Electron-coupled Oscillator

An oscillator circuit usually cannot provide appreciable power without change in frequency. Thus the output must be amplified before being used. For frequency stability, it is desirable to keep the output plate circuit of the oscillator from affecting the grid circuit in any

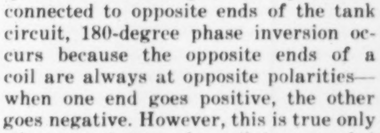


Fig. 17. Ultraudion oscillator.

Table 3.—DECADE CLASSIFICATION OF RADIO WAVES

Frequency, kc	*Wavelength, meters*	*Designation*
10 to 30	30,000 to 10,000	Very low frequency (VLF)
30 to 300	10,000 to 1,000	Low frequency (LF)
300 to 3000	1,000 to 100	Medium frequency (MF)
3000 to 30,000	100 to 10	High frequency (HF)
30,000 to 300,000	10 to 1.0	Very high frequency (VHF)
300,000 to 3,000,000	1.0 to 0.1	Ultrahigh frequency (UHF)
3,000,000 to 30,000,000	0.1 to 0.01	Super high frequency (SHF)

way. This is done in the electron-coupled oscillator (Fig. 18) by using a screen at a fixed potential. The fixed-potential screen shields the grid from r-f. plate-circuit variations, thus permitting stable grid-circuit action. The name "electron-coupled" arises from the fact that the only coupling between plate and grid circuits is by the plate-current beam of electrons. The oscillator thus is a combined Hartley oscillator and amplifier. Load variations (changes in power output) do not effect the frequency, as they would if there were coupling between plate and grid circuits.

Another advantage of the electron-coupled oscillator is that changes in screen potential affect the frequency opposite to the way that changes in plate potential do. Thus the circuit can be made independent of supply-voltage variations.

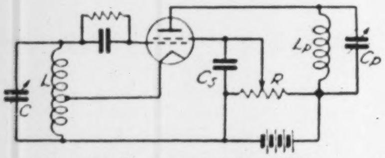


Fig. 18. Electron-coupled oscillator.

The electron-coupled circuit can be used as a *frequency multiplier* by tuning the plate tank to a harmonic of the natural resonant frequency of the grid tank. The grid tank then resonates at its fundamental frequency, but the plate tank oscillates at the harmonic frequency.

Crystal-controlled Oscillators

Oscillators that use resonant *L-C* tanks change frequency with change in load, supply voltage, or ambient temperature. Even the stability of electron-coupled oscillators is not high enough for many applications. Where the frequency must be highly stable, a *piezoelectric crystal* is used as the resonant tank, as shown in Fig. 19. The circuit is a tuned-plate tuned-grid oscillator. The resistor in the grid circuit is a grid-leak-bias resistor; the inductor is simply a radio-frequency choke.

The crystal is a substance (such as quartz, Rochelle salt, or tourmaline) which develops a charge across its faces when subjected to compression or tension. Conversely, when connected to a source of potential, the crystal changes shape.

The mechanical-electrical properties of piezoelectric crystals enable them to oscillate with little energy loss and with high frequency-stability. As the oscillating crystal is a mechanical oscillator with mass, elastance, and internal damping, the frequency of oscillation depends on the mass, elastance and dimensions, particularly the thickness. The natural resonant frequency increases as thickness decreases. Crystal frequencies are normally from ultrasonic frequencies to about 100 Mc. The crystal-controlled oscillator can produce only frequencies that are the same or harmonics of the natural frequency of the crystals used in the circuit.

The power obtainable is limited at high frequencies (megacycles per sec.) by the heat developed inside the crystal, and at low frequencies by the large amplitudes of vibration, which can crack the crystal. The amplitude of vibration depends on the amount of signal fed back into the grid circuit; the small amount fed back across the small plate-grid capacitance of a tetrode is sufficient to sustain oscillation.

As the crystal is a mechanical oscillator, the crystal holder must contribute as little damping as possible. The crystal can be operated in a temperature controlled holder to obtain a stability of 10 parts in a million. Stability of one part in a million can be obtained by temperature control of the entire circuit and by use of all possible precautions.

Tuning-fork Oscillator

The tuning-fork oscillator, like the crystal oscillator, is a stable electromechanical resonator. The frequency is determined by the resonant frequency of the fork. Whereas crystal-controlled oscillators can operate from ultrasonic to high radio frequencies, the tuning-fork oscillator is used as an audio-frequency oscillator, usually developing 400, 440, or 1000 cps. They are characterized by good sinoidal waveform and frequency stability of about one part in a thousand.

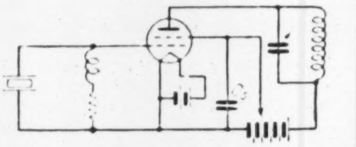


Fig. 19. Crystal-controlled oscillator using tetrode.

Magnetostriction Oscillator

Some metals, such as nickel and nickel alloys, change shape when placed in a magnetic field. Also, when they are forced by mechanical means to shrink or expand, they change the magnetic field they are in. This effect is called magnetostriction.

The circuit of a magnetostriction oscillator is similar to a Hartley oscillator, except that grid and plate coils are arranged to *prevent* feedback. Thus no oscillation can occur until the magnetostrictive rod is inserted in the coils. When the resonant frequency of the resonant tank is near the mechanical resonant frequency of vibration of the bar, a mechanical oscillation is produced in the bar. Frequencies to several hundred kilocycles per second can be produced in this manner. This is a source of ultrasonic energy for industrial and military (sonar) applications. The term "transducer" was first applied to piezoelectric and magnetostriction oscillators used to produce high-energy ultrasonic waves for underwater sonar (sound navigation and ranging) applications.

Negative-resistance Oscillators

In all oscillators, energy is fed back into the circuit to overcome losses in the circuit. As losses occur mainly because of resistance, the energy fed back can be considered a form of negative resistance that cancels the real, or positive, resistance in the circuit.

If the voltage across and the current through a resistor are plotted, the graph is a straight line with positive slope. Several devices show a negative slope when their voltage-current characteristic is plotted in this manner. For example, the plate characteristic of a tetrode has a region of negative resistance. Any device that has a negative-resistance characteristic can be used to cancel real resistance and thus sustain oscillation in an oscillator.

Dynatron Oscillator

Fig. 20 shows how the tetrode is used as a *dynatron* oscillator. The resonant tank is connected to the plate. As the screen is at a higher potential than the plate, secondary emission electrons cause the plate current to *decrease* when plate voltage increases. This negative-resistance characteristic sustains the oscillation. The dynatron is simple, can be used from low audio frequencies to about 15 Mc., and has high stability and good waveform. The disadvantages are low power output and variation in "negative-resistance" tube characteristic with age of tube and between tubes of the same type.

Transitron Oscillator

The transitron oscillator (Fig. 21) uses a pentode with the screen grid coupled to the suppressor. As in the dynatron, the screen is at a higher potential than the plate. When screen potential is increased, it is found that there is a region in which screen current decreases because the negative suppressor repels fewer electrons to the screen. The tube is operated in this negative-resistance region and the resonant tank is connected to the screen.

The transitron, like the dynatron, is a low-power device. However, as it does not use secondary emission as an operating principle, it is more stable than the dynatron; its frequency stability is comparable to that of a crystal oscillator without temperature control.

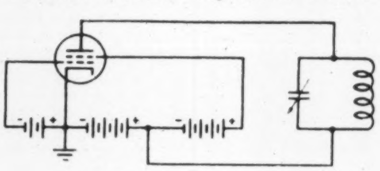


Fig. 20. Dynatron oscillator.

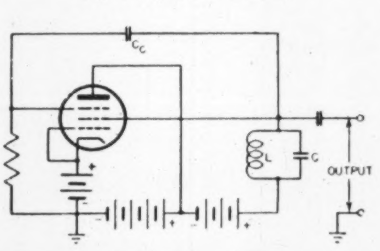


Fig. 21. Transitron oscillator.

Another advantage is a wide frequency range; it is used from low-audio frequencies to above 60 Mc.

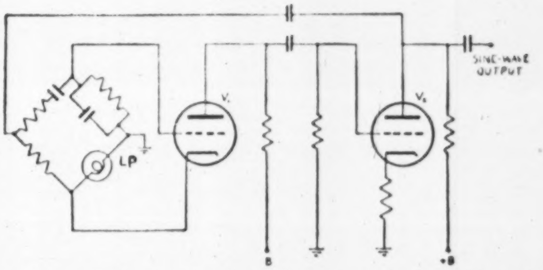


Fig. 23. Wien-bridge oscillator.

Resistance-capacitance Oscillators

A resonant device was used in all the oscillators described. However, any amplifier can be made to oscillate by feeding output energy into the input if the signal fed back has (1) the same polarity as the signal without feedback and (2) the same amplitude as the signal without feedback. This type of self oscillation often is encountered in all "closed-loop" systems, such as servomechanisms, controllers, etc. There may be no resonant element because oscillation is not desired; however, whenever the two conditions are met, oscillation occurs whether it is desired or not. This principle is used in resistance-capacitance oscillators, which use *R-C* circuits to produce the phase inversion required to make the feedback signal the same polarity as the input signal.

Phase-shift Oscillator

Fig. 22 shows an amplifier with a 3-section *R-C* network between plate and grid. Each section produces a 60-degree phase shift in signal. Thus the phase shifter produces a 180-degree change in phase. As the plate signal is 180 degrees out of phase with the grid signal, the total phase shift is 360 degrees and oscillation occurs.

The oscillation occurs only at the one frequency at which the 360-degree phase shift occurs. The frequency can be changed by altering any of the resistors or capacitors in the phase-shift network. The circuit is characterized by good sinoidal waveform and high frequency-stability when small oscillations are produced. It is used in audio-frequency signal generators because it is tunable over a wide range of audio frequencies and because parallel-resonant *L-C* tanks become too bulky at audio frequencies.

Wien-bridge Oscillator

In the Wien-bridge oscillator (Fig. 23) a frequency-selective Wien bridge is used to select only one frequency for feedback. As two amplifier stages are used, the feedback signal from the plate of the second tube is in phase with the grid signal of the first tube and, therefore, oscillation at any frequency can occur. However, the bridge circuit selects only one frequency.

Note that a signal is fed both to the grid and cathode of the first tube. The grid signal is regenerative; the cathode signal is degenerative. The one frequency at which the former exceeds the latter becomes the resonant frequency. The lamp in the cathode circuit of tube V_1 stabilizes the amplitude of oscillation because its resistance increases if plate current increases, thus reducing the amplitude.

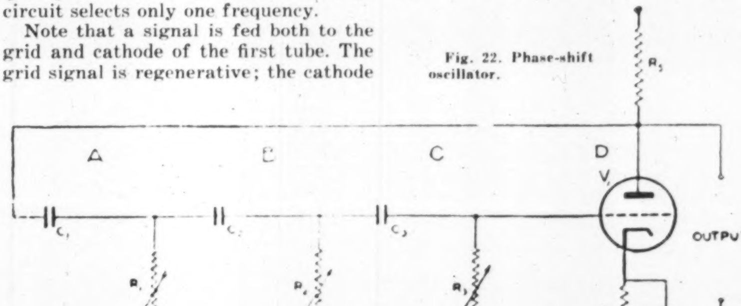


Fig. 22. Phase-shift oscillator.

The Wien-bridge oscillator is used commonly in audio test-signal generators. It operates over a wide range of frequencies, it has excellent stability, and the output amplitude is constant over a wide range of frequencies.

In recent years the RC Wien-bridge and RC phase-shift oscillators have become dominant as test oscillators in the range from 0.01 cps. to 10 Mc. because of numerous advantages—(1) with all tubes operating Class A, distortion can be kept low with inexpensive components, (2) with a simple nonlinear resistive element such as a Type 6S6 lamp, the output level can be maintained within a fraction of one db over a frequency range of 10,000 to 1, (3) as there are no inductors, frequency calibration is relatively easy, and optimum results can be obtained at any frequency within its range, irrespective of "L to C ratio" or "Q of tank circuit," and (4) the frequency is proportional to C, instead of $\sqrt{C}$, thus permitting wide coverage of frequency within one instrument.

Relaxation Oscillators

Relaxation oscillators use the charging and discharging of capacitors to produce trigger action and sawtooth waveforms.

Neon Sawtooth Generator

The simplest sawtooth generator is the neon relaxation oscillator shown in Fig. 24. A high positive potential is applied at B+. The potential charges capacitor *C* through resistor *R* at a rate determined by the *RC* time-constant. When the voltage across *C* exceeds the firing potential of the neon glow tube, the tube ionizes and the capacitor discharges rapidly through the tube. The tube acts like a switch which is open when it is not ionized and closed when it is ionized.

When the tube fires, the capacitor discharges and the voltage falls rapidly until it reaches the deionizing potential of the tube, at which point the gas deionizes and the capacitor starts charging again. Thus the amplitude limits of the output sawtooth waveform are the ionizing and deionizing potentials of the tube and cannot be altered. The frequency (number of sawtooth waveforms per second) is controlled by the adjustment of either *R*, *C*, or supply voltage. The frequency can be increased by decreasing *R* or *C*, or by increasing the supply voltage.

Thyratron Sawtooth Generator

A relaxation oscillator that uses a thyratron instead of a neon tube is shown in Fig. 25. The circuit action is the same as for the neon oscillator; however, the grid of the thyratron offers convenient control of the firing potential and thus of the amplitude of the generator output.

A disadvantage of the thyratron is that when the grid bias is changed to control the firing potential of the tube, the frequency changes also. The frequency can be changed without affecting the amplitude by changing the charging resistor, capacitor, or voltage, as in the neon sawtooth generator.

In addition to amplitude control, another advantage of the thyratron is that the firing can be ***synchronized*** (stabilized) by an external (sync) signal of high stability. When the sync

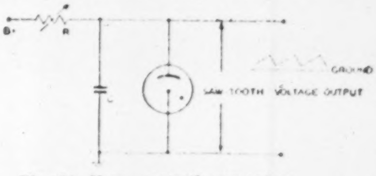


Fig. 24. Neon sawtooth generator.

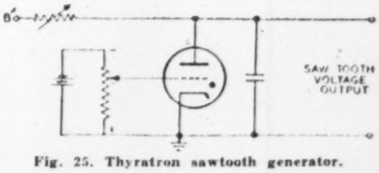


Fig. 25. Thyratron sawtooth generator.

signal (usually a sine wave) is applied to the grid, the firing potential can be altered slightly; the tube then fires at one point on the applied sync signal. The sync signal can stabilize the generator only at a frequency that is higher than the natural frequency without synchronization because the sync voltage can make the thyratron fire sooner, but not later, than its natural frequency. The generator can be synchronized, or *locked*, to the same frequency, to a submultiple, or to a multiple of the injected sync voltage.

Note that the output waveform of a relaxation-type sawtooth generator is a capacitor-charging voltage. Thus the output has an exponentially rising shape. By using a d-c. supply voltage much higher than the firing voltage of the tube, a linear rise is obtained.

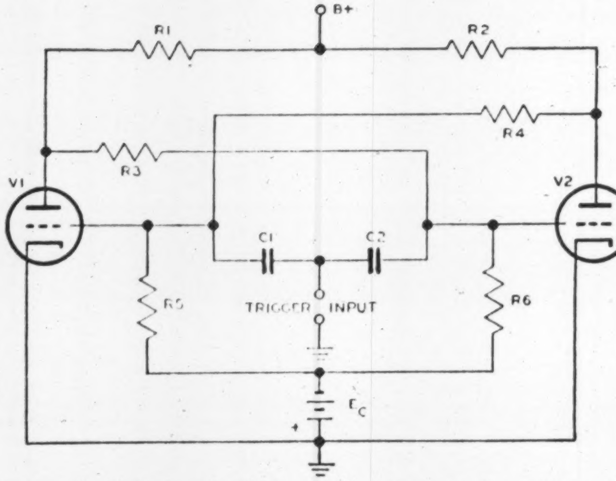


Fig. 27. Eccles-Jordan flip-flop trigger circuit. This bistable device is the heart of many binary-type counters and computers.

The Multivibrator

The multivibrator is a form of relaxation oscillator used frequently in switching and timing circuits. It produces a square-wave output and is called a square-wave generator or electronic switch. There are two types—free-running and driven.

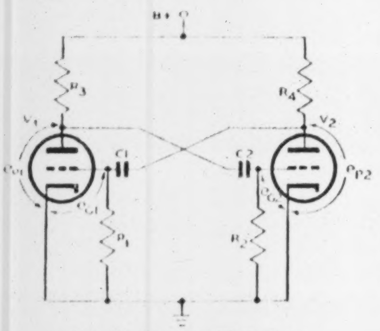


Fig. 26. Basic multivibrator.

The basic free-running multivibrator is shown in Fig. 26. Note that the plate of each tube is connected to the grid of the other through a capacitor.

Assume a small negative signal on the grid of V_1. This causes a positive amplified signal at the plate of V_1. This signal causes a further amplified negative signal at the plate of V_2, which is fed back to the grid of V_1. This action causes the grid of V_1 to go far negative quickly and cut off the tube, at which time there is no signal at its plate. The negative charge on the grid of V_1 now leaks off through R_1. As soon as the cut-off point is reached, plate current starts to flow, starting another half cycle of operation. Thus each tube is alternately full conducting and then cut off. As the circuit is not in equilibrium in either condition, the process keeps repeating with a period determined by the R_1C_1 and R_2C_2 time constants. The output waveform at the plate of either tube is similar to a square wave. When R_1C_1 and R_2C_2 are the same, the square wave is symmetrical—that is, of equal duration on each half cycle of operation.

Synchronization

As the frequency-stability of the free-running multivibrator is poor, multivibrators in timing and sweep circuits usually are *driven*—that is, synchronized by an external waveform. A stable sine wave or an accurately timed series of pulses can be applied to the cathode or grid of either tube. The synchronizing voltage causes the tube to "switch" at one point on the applied sync signal, thus locking the multivibrator to the frequency of the applied signal.

The multivibrator can be synchronized to a fraction (or half, one third, etc.) of the driving frequency. This permits *frequency division.*

Eccles-Jordan Flip-flop Trigger Circuit

The Eccles-Jordan trigger circuit (Fig. 27) is a basic trigger circuit that has two conditions of equilibrium. A positive or negative trigger pulse causes the circuit to "flop" from one condition to the other.

The circuit is similar to the basic multivibrator, except that the plate of each tube is connected to the grid of the other tube through a resistor. Thus the d-c. grid potential depends on the plate potential.

If V_1 is nonconducting, its plate is at a high potential. This causes the grid of V_2 to be very positive and V_2 to be conducting. This is one of the two equilibrium conditions.

A positive trigger causes nonconducting V_1 to conduct slightly. This causes a negative plate signal at V_1 and a larger positive plate signal at V_2. This regenerative action quickly causes V_1 to become conducting and V_2 to be nonconducting. This is the other equilibrium condition. Another positive trigger acts on V_2, starting another "flip-flop" of the circuit. The flip-flop action is the same as in the multivibrator.

A negative trigger also can cause flip-flop action because it affects the conducting tube, causing a decrease in plate current and the initiation of flip-flop trigger action.

As two pulses are required for a complete cycle, the circuit is a scale-of-two counter. It is used in binary (scale-of-two) counting.

Beat-frequency Oscillators

A basic use of oscillators is changing the frequency of a sine wave by heterodyning. *Heterodyning* refers to the mixing of two sine waves of different frequency. When two such waves are fed into a nonlinear device (such as an unbiased tube or a diode), the output contains not only the two input frequencies, but also frequencies equal to the *sum* and *difference* of the two input frequencies. Thus a wave of any frequency can be heterodyned to a lower or higher frequency without altering its amplitude configurations.

This principle is used in all superheterodyne radio receivers and in the beat-frequency oscillator (BFO). In the superheterodyne receiver, the radio-frequency signal is lowered to an inter-

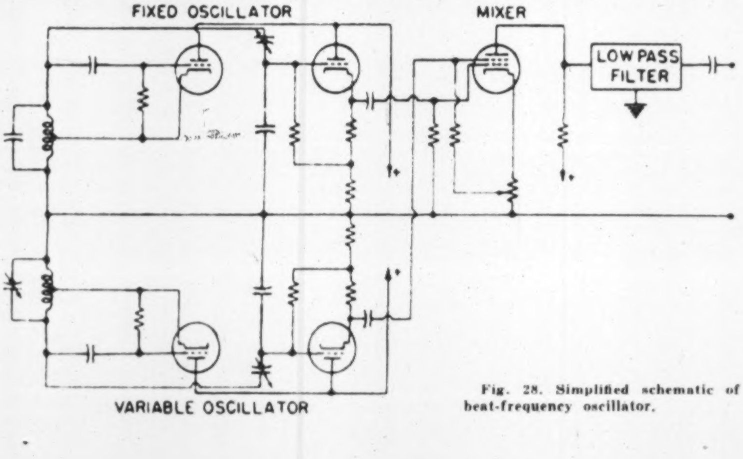


Fig. 28. Simplified schematic of beat-frequency oscillator.

mediate frequency by heterodyning the r-f. carrier wave with a signal from a local oscillator in the receiver. The lower intermediate-frequency signal then is amplified and demodulated into audio-frequency signals.

In the beat-frequency oscillator (Fig. 28), two high-frequency oscillators are heterodyned. The difference frequency, or *beat frequency*, in the output can be a low-frequency audio signal. By changing one of the oscillators, a large percentage change in frequency of output is obtained.

In order to produce sum or difference frequencies by heterodyning two frequencies, it is necessary that the mixing device be nonlinear—that is, a better conductor in one direction than in the other. A diode or an amplifier tube with a nonlinear characteristic can be used. Special tubes with several grids for mixing signals are called mixers, or pentagrid converters.

Shock-excited Oscillator

Fig. 29 shows a resonant tank in the cathode circuit of a tube. As the grid is at a positive potential, the tube is normally conducting.

If a large negative signal is applied at the input, the plate current is interrupted suddenly. The resonant tank then is *shocked* into oscillation, which gradually dies out—that is, the output is a damped oscillation. The oscillator sometimes is called a *ringing* oscillator.

The circuit would provide an output if the tube were non-conducting and if a positive pulse were applied at the input. However, the oscillation would die out more rapidly because the low conducting plate-resistance of the tube is effectively in parallel with the tank. When the tube is suddenly cut off, the tube is a high resistance in parallel with the tank and does not provide much damping.

The circuit is used in timing and radar applications by applying an accurately timed negative pulse (called a *gate* pulse) at the input. Thus a precise number of oscillations can be obtained for the duration of the gate pulse.

UHF Oscillators

Resistance-capacitance oscillators and beat-frequency oscillators can produce audio frequencies. Crystal-controlled and magnetostriction oscillators can produce ultrasonic frequencies. Oscillators with conventional parallel-resonant *L-C* tanks operate satisfactorily up to about 100 Mc.; above this frequency, however, the capacitance and inductance become too small for practical use.

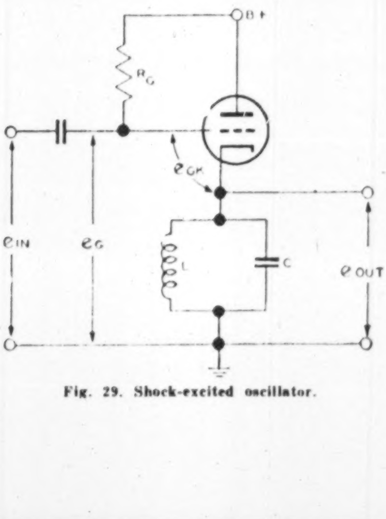


Fig. 29. Shock-excited oscillator.

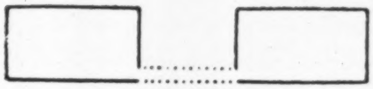


Fig. 30. Cavity resonator.

Butterfly Tanks

Above 100 Mc., the inductor can be made into a single turn, and the rotor plates of the capacitor can be shaped like a butterfly. Motion of the rotor plates fills the air space and varies both the inductance and the capacitance. In practice, one knob varies both. Butterfly tanks are used with acorn and doorknob tubes for frequencies up to several thousand megacycles per second. Above this frequency special tubes that utilize electron transmit time (klystrons and magnetrons) are used with cavity resonators as the resonant element.

Cavity Resonators

Cavity resonators are the resonant tanks used at microwave frequencies—that is, above 1000 Mc. The most common type resonant cavity is the *reentrant cavity*, shown in Fig. 30.

The term "reentrant" refers to the fact that a section of the cavity is directed inward and made narrow. The narrow section is made of a grid or lattice so that electrons can pass through. If electrons pass through in bunches, they excite electromagnetic oscillation in the cavity. The shape and size of the cavity determine the resonant frequency; the reduced section is primarily capacitive, the outer volume is primarily inductive. A tuning method consists of changing the width of the capacitive gap. The trade-name "Rhumbatron" is used sometimes to identify resonant cavities.

In order to excite oscillation in the cavity, electrons must pass through or near the gap at appropriate intervals. Electron transit time from cathode to plate, which is the factor that prevents conventional tubes from operating at microwave frequencies, thus is utilized to produce oscillation. Klystron and magnetron oscillators often are constructed with built-in cavity resonators.

The principle of operation of all velocity-modulated tubes, klystrons and magnetrons is interaction of the electron beam and the electromagnetic field produced in the resonant cavity. As electrons pass near the cavity, oscillation (electromagnetic field) is induced in the cavity. This field acts on the electrons, accelerating electrons on positive peaks and decelerating them on negative peaks. It is this interaction between field and electrons that produces electron bunches. The bunches then produce strong oscillations when they sweep through the cavities.

Klystron

Fig. 31 shows the operation of a klystron. Electrons leave the cathode and travel through the buncher and catcher cavities. As they pass through the first reduced section, or *buncher* grids, they induce a resonance in the first (buncher) cavity. As the electrons travel through the *drift space*, slow electrons lag behind fast electrons and groups of electrons are formed. The groups pass through the catcher grids and excite strong oscillation in the upper (catcher) cavity. This cavity provides both the output and feedback signal. When feedback from the output to the input terminal is of proper polarity, a microwave oscillation is sustained. The first cavity is called a buncher because it causes the bunching of electrons in the drift space.

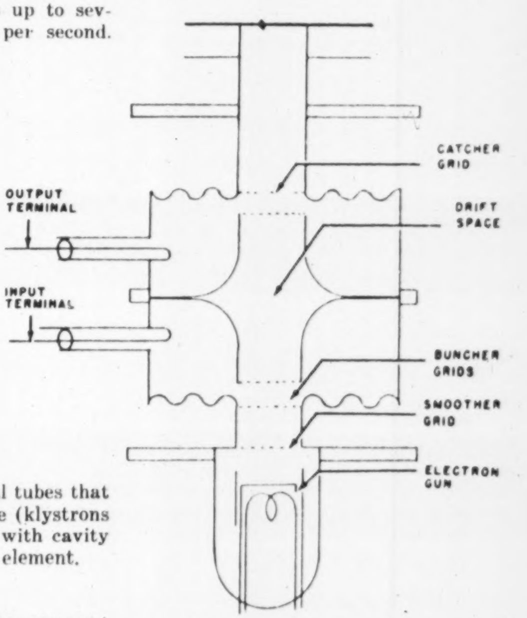


Fig. 31. Klystron.

In the *reflex klystron*, a negative plate repels the bunches so that they pass through the single cavity in the opposite direction. Thus one cavity serves as both buncher and catcher. This type is used widely as a local oscillator in UHF radar receivers.

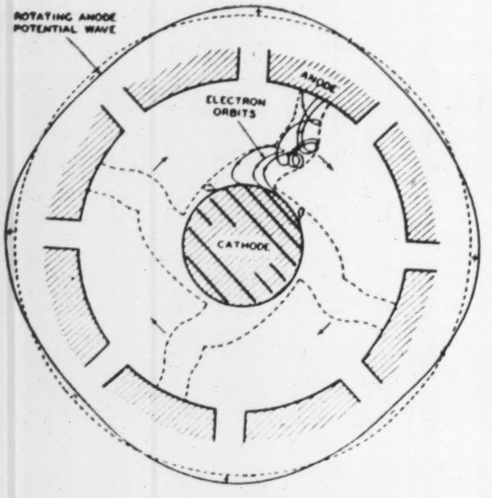


Fig. 32. Path of electrons in magnetron.

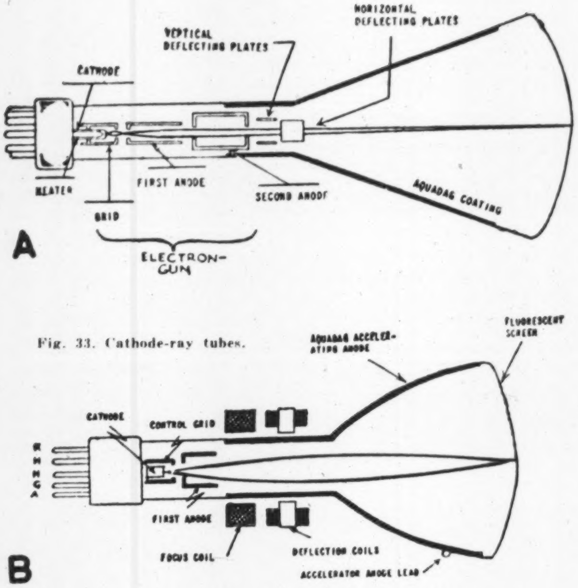


Fig. 33. Cathode-ray tubes.

Magnetron

The magnetron, like the klystron, is a velocity-modulated vacuum tube that uses motion of electron bunches to induce oscillations in a microwave resonant cavity. However, the bunches of electrons are formed by bending the electron beam with a strong magnetic field directed perpendicular to the direction of motion of the electrons. The magnetic field causes the electrons to travel in a cyclical path, as shown in Fig. 32. As the electrons pass the openings leading to the resonant cavities, they induce oscillation in the cavities. The electromagnetic field in turn causes the electrons to form bunches. The electron bunches travel in cyclical paths from cathode to anode and also rotate around the cathode. They pass each opening to each resonant cavity at the proper instant to induce and sustain oscillation in the cavity. The output is taken from a small pickup loop brought near one of the cavities. Strong oscillations are developed in the cavities, which are a part of the anode block of the magnetron.

The magnetron is particularly useful as a generator of high-power pulses of microwave energy. It is the source of high-power pulses of UHF energy in most military and navigation radars.

3. THE CATHODE-RAY OSCILLOSCOPE

This instrument uses a cathode-ray tube for making signals visible. It has great utility as a servicing tool because it permits, as no other instrument does, visual observation of the shape and waveform of the signal in a circuit. The principles of the CRO are used also in television and radar.

The cathode-ray tube (Fig. 33) has an electron gun that produces a beam of electrons. The beam is focused so that it strikes a fluorescent screen at a point. The point of impact is visible because light is emitted when the beam of electrons strikes the fluorescent material.

The oscilloscope makes it possible to "see" rapidly changing electrical voltages because the electron is the lightest known mass and yet is endowed with a charge. Owing to its infinitesimal mass, it has negligible inertia and can be started, moved, and stopped with negligible delays (in the order of thousandths of a microsecond). The charge on the electron makes it possible to accelerate and decelerate the electron by bringing a voltage (an electric field) near the electron. This is done in the cathode-ray oscilloscope by applying the signal to be observed to the vertical-deflection plates (through an amplifier). Variations in voltage of this signal cause the spot to move vertically in instantaneous response to the signal variations. At the same time, the spot is swept horizontally across the screen (from left to right) by a *sweep signal* applied to the horizontal-deflection plates. The result is a pattern on the screen, showing the waveform of the signal applied to the vertical-deflection plates. Fig. 34 shows 4 cycles of an applied sine wave; this pattern is produced when the horizontal sweep frequency is ¼th the frequency of the signal observed.

Cathode-ray Tubes

Types. There are two types of cathode-ray tubes—electrostatic and magnetic. The electrostatic cathode-ray tube, shown in Fig. 33A, uses electric fields to focus the beam and to deflect the spot both horizontally and vertically. As an electron can be deflected by a magnetic field as well as by an electric field, magnetic fields produced by current in coils around the neck of the tube can perform the same functions as the electrostatic fields produced by the plates inside the electrostatic tube. Fig. 33B shows a CRT that uses magnetic fields to focus and deflect the beam. The *focus coil* in the magnetic type produces the field that focuses the beam. Two crossed pairs of coils in the *deflection coil* are used for vertical and horizontal deflection of the spot.

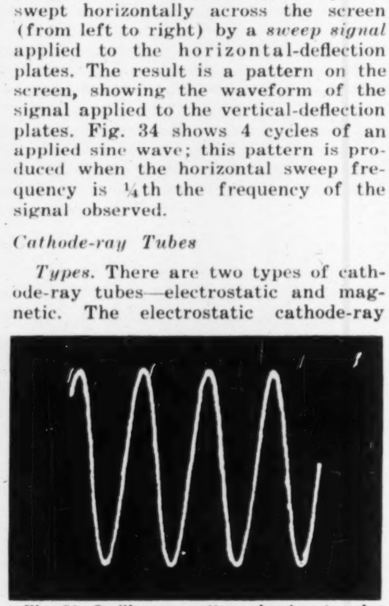


Fig. 34. Oscilloscope pattern showing 4 cycles of a sinoidal signal.

The advantages of magnetic control are (1) tube simplicity, (2) tube ruggedness, (3) shorter tube length, and (4) greater deflection of spot for large-face tubes. Thus magnetic control is used in television receivers and radar indicators that use large-size cathode-ray tubes.

The advantages of electrostatic control are (1) a simpler deflection circuit and (2) less power consumption by the deflection circuit. Most oscilloscopes use electrostatic control.

Electron gun. This term refers to the cathode, filament, grid, and first two anodes, which produce the collimated beam. The first and second anodes focus the electrons into a sharp beam. The first anode often is called the *focusing* anode; the second anode often is called the *accelerating* anode. Although both electrodes accelerate and focus the beam, the first-anode potential is varied to adjust the focusing.

The inside of the tube is coated with electrically-conducting *Aquadag*, which serves as the return path for secondary electrons emitted when the beam strikes the screen. The highest positive potential in the circuit is applied to this coating to help accelerate the electrons to a high velocity so that the spot is brilliant. This lining is referred to as the accelerating lining (because it accelerates the electrons) or as the intensifier lining (because it intensifies the beam). In some oscilloscopes a metal anode, called an *intensifier ring*, is cemented to the inside of the glass and no Aquadag coating is required.

Fluorescent screen. The screen consists of chemicals deposited on the inside face of the cathode-ray tube. Tubes are available with materials that fluor-

TABLE 4. STANDARD RTMA PHOSPHORS

Screen	Persistence	Composition	Fluorescence	Phosphorescence	Applications
P1	Medium	Zinc orthosilicate	Green	Green	Visual observation. High efficiency of P1 screen results in bright traces at relatively low accelerating potentials.
P2	Long or short	Zinc sulphide	Blue-green	Yellow-green	General purpose screen for oscillographs employing accelerating potentials of 4,000 volts or more. High efficiency for high-speed single transients.
P3	Medium	Zinc Beryllium silicate	Yellow	Yellow	General oscillographic use. Not as efficient as P1. Persistence has exponential decay that is chiefly of interest in television.
P4	Medium	Zinc sulphide and zinc beryllium silicate	White	White	Used primarily for television picture tubes.
P5	Short	Calcium tungstate	Blue	Blue	Used primarily for photography on continuous-motion film for frequencies above 200 kc. Not as actinic as P11.
P6	Medium	Zinc sulphide and a complex compound of zinc and calcium sulphide	White	White	Developed chiefly for use in color television.
P7	Long or short	Zinc sulphide cascaded on zinc and calcium sulphide	Blue-white	Yellow	Developed originally for radar. Similar in characteristics to P2 screen, but has longer persistence. Useful for radar, integrating noise, and repetitive phenomena and low speed transients.
P8	Same as P7				
P9	Long	Calcium phosphate	White	White	Very long persistence with high definition, developed primarily for radar applications.
P10	Nearly permanent	Potassium chloride	Magenta on White	Magenta on White	Used chiefly for radar. Pattern erased by infra-red irradiation.
P11	Short	Zinc sulphide	Blue	Blue-green	Used primarily for oscillographic recording; has higher visual and photographic efficiency than P5, but persistence is slightly greater than P5.
P12	Long	Zinc magnesium fluoride	Orange	Orange	Used primarily for fire-control radar for scanning rates of from 4 to 16 scans per second.
P14	Long	Zinc sulphide cascaded on ZnS and CaS	White	Orange	Developed for radar operating at a scanning rate of about 1 scan per second. Also for moving-target indication.
P15	Very Short	Zinc oxide	Blue-green	Blue-green	Shortest persistence presently available. Used primarily in flying-spot scanners or for high-resolution, high-frequency continuous motion recording. Not as actinic as P11.
P17	One component extremely short Other component long	Zinc oxide cascaded on P7 screen	Greenish-yellow	Yellow	Used chiefly for radar. Has more light output than P7 screen.
P19	Very long	Magnesium fluoride	Orange	Orange	Radar indication, particularly for night application.

esce with green, white, blue or yellow color; green and white are used most commonly. After the impact of an electron, the glow persists for a fraction of a second. The duration of the afterglow, or *persistence*, is what makes the trace visible. Tubes of various persistence are available (see Table 4).

Positioning. The spot can be positioned anywhere on the face of the cathode-ray tube by (1) changing the d-c. operating potential of the deflecting plates in electrostatic tubes or (2) changing the direct current in the deflection coils of magnetic tubes.

Intensity. The intensity of the beam is controlled, or modulated, by adjusting the grid-cathode bias, which determines the number of electrons in the beam. This intensity modulation of the beam often is referred to as the Z axis of the tube—that is, the spot can be varied horizontally (X-axis), vertically (Y-axis), or in intensity (Z-axis).

Components of Oscilloscope

Fig. 35 shows the basic components of an oscilloscope—(1) cathode-ray tube, (2) horizontal-deflection amplifier, (3) vertical-deflection amplifier, (4) sweep generator, and (5) power supply.

Sweep Circuit. For observing a signal, the spot is swept across the tube from left to right. The spot then is returned rapidly to its starting point; the spot is blanked out during the small interval in which it "retraces" to its starting point. Except for this short retrace interval, all signal variations can be seen on the screen.

The sweep generator provides the signal that sweeps the spot horizontally across the tube. It usually is a relaxation oscillator that produces a linear sawtooth waveform. It is adjustable in frequency of operation, and is provided with means for synchronizing the sweep generator with any external signal. This is called *external sync*. The sweep generator can be synchronized also with a portion of the signal taken from the vertical-deflection circuit. This *internal synchronization* causes the sweep generator to oscillate at exactly the same frequency (or a submultiple) of the signal to be observed, resulting in a stable, visible pattern.

Deflection amplifiers. The vertical-deflection amplifier amplifies the signal to be observed. It usually is a wide-band R-C-coupled video amplifier with push-pull output for driving the two vertical-deflection plates in opposite polarity.

The horizontal-deflection amplifier amplifies either the signal from the sweep generator (when an internal sweep-signal is used) or any external signal applied to the input posts marked HORIZONTAL INPUT. As it usually receives the large signal from the sweep generator, the horizontal-deflection amplifier does not require as much gain as the vertical-deflection amplifier, which receives unknown signals of all amplitudes. The horizontal-deflection amplifier, like the vertical-deflection amplifier, has push-pull output for driving the two horizontal-deflection plates in opposite polarities.

As the horizontal- and vertical-deflection amplifiers of most oscilloscopes are R-C coupled, they cannot handle d-c. signals. Therefore, the deflection plates usually are connected to external posts so that d-c. signals can be observed by applying them directly to the posts (Fig. 35). As no amplification precedes signals applied directly to these posts, only signals of relatively large amplitudes (volts) can be observed in this manner. In other words, the *deflection sensitivity* of the defle-

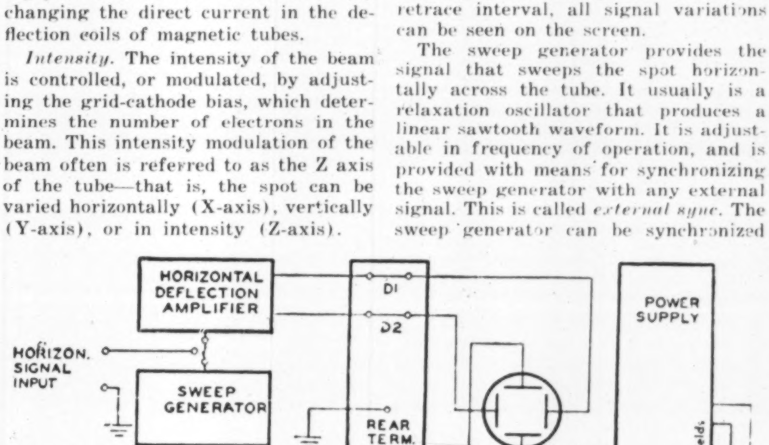


Fig. 35. Basic components of a cathode-ray oscilloscope.

tion plates is several volts per inch deflection. Some oscilloscopes provide for d-c. amplification.

Power Supplies. The power supply must supply conventional plate and screen potentials of several hundred volts, and a high potential for the accelerating and intensifier (Aquadag) anodes. In conventional oscilloscopes the accelerating potential is about 1500 volts; the intensifier voltage is about 3000 volts.

Typical Oscilloscope Characteristics

The following characteristics emphasize the important features and responses of a typical test oscilloscope:

X and Y amplifiers. Response down less than 10 percent at 100,000 cps.; less than 50 percent to 300,000 cps. This means that both X and Y amplifiers are useful for observing waveforms with frequency above 300,000 cps.

Vertical deflection factor. Through vertical amplifier at full gain: 0.01-rms. volt input signal causes 1-inch vertical deflection of spot. When signal is applied direct to plates: 18-rms. volts produce 1-inch vertical deflection.

Horizontal deflection factor. Through X-axis amplifier: 0.05-rms. volt per inch. Direct to plates: 21-rms. volts per inch.

Sweeps. Recurrent and driven linear sweeps variable in frequency from 2 to 30,000 cps. Provisions for extra-low-frequency sweeps. Return trace automatically blanked. Sweep may be synchronized by signal of either polarity. All sweeps can be expanded to six times screen diameter for study of high-frequency components of low-frequency signals.

Intensity modulation. External negative signal of 15 volts (peak) will blank beam at normal intensity settings.

Uses

The oscilloscope is one of the most useful tools in the laboratory or instrument department. It combines the functions of several instruments and can perform a variety of tasks. It has five basic uses—(1) observation of waveform, (2) measurement of frequency, (3) measurement of phase, (4) measurement of voltage, and (5) measurement of time.

The primary use in observation of waveform; signals can be traced through a circuit and sources of distortion can be found merely by observing the signal at various points in a circuit.

Another important use is the determination of the *frequency* of an unknown signal by comparison with a signal of known frequency. For this application no sweep signal is used. The known signal is applied to one set of deflection plates and the unknown is applied to the other set. Fig. 36 shows patterns for various ratios of frequencies. Note that the ratio of frequencies is found from the number of times that the waveform reaches a maximum in horizontal and vertical directions.

When two waves of the same amplitude and frequency are applied to the deflection plates, variations in *phase* between the waves produce the patterns shown in Fig. 37. The phase relation of the signals is observable from the pattern.

The oscilloscope can be used as a *voltmeter* for d-c. or a-c. signals by calibrating the deflection-plate sensitivity or deflection amplifiers.

For *time measurement*, the linear horizontal sweep is used. As the sweep is a linear time base, the duration of signals as well as the duration between signals can be measured. This is the basis of radar, in which the time for a pulse to travel from transmitter to target and for the echo to return to the receiver is indicated in terms of a displacement of a signal on the face of a CRT. This also is the principle of ultrasonic thickness gages.

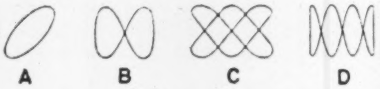


Fig. 36. Lissajous patterns produced when signals of different frequencies are applied to the two deflection systems. Ratio of frequencies in A is 1:1, ratio in B is 2:1, ratio in C is 3:2; ratio in D is 4:1.

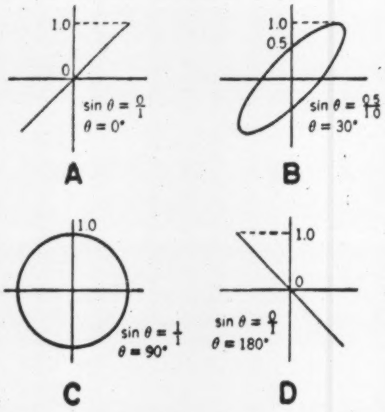


Fig. 37. Patterns when signals of same frequency but different phase are applied to the two deflection systems. A, phase difference is 0 deg.; B, phase is 45 deg.; C, phase is 90 deg.; D, phase is 180 deg.

Some jobs performed regularly by oscilloscopes (with auxiliary apparatus) are: Measurement of phase shift across electric wave filters, measurement of bias distortion of teletype signals, measurement of inductance to 0.1 percent when used with precision capacitors, null-detector indicator, measurement of distortion in amplifiers, measurement of the Q or dissipation factor of capacitors, measurement of reflected impedance, measurement of voltage-ratio of transformers, adjustment of decimal counting unit, frequency monitoring, etc., etc.

Synchroscope. An oscilloscope with a single sweep that is generated only when a synchronizing signal is provided is called a synchroscope. Synchroscopes are useful for observing short pulses which may or may not be repetitive. The pulse to be observed is fed to the vertical-deflection plates through a delay device that delays it for a period of microseconds. During the delay period, the pulse triggers the sweep, so that the spot is near the center of the tube before the deflection occurs. Note that the oscilloscope described previously has a driven, as well recurrent, sweep available. Hence this test oscilloscope can be called a "synchroscope."

Maintenance

If not maintained properly, oscilloscopes develop troubles which show up in failure of the instrument to provide:

1. *Correct sensitivity (gain)*, to permit the oscilloscope to be used as a VTVM when its sensitivity in inches deflection per rms. volt is known.

2. *Correct frequency response.* Most modern oscilloscopes have useful sensitivity to above 200 kc.; special pulse oscilloscopes operate flat to several megacycles.

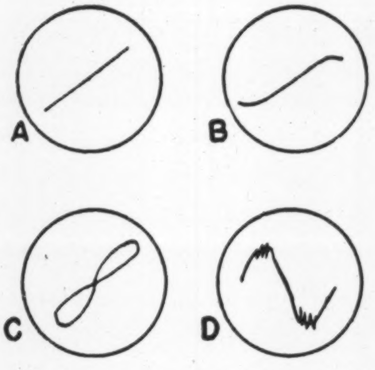


Fig. 38. Typical patterns. A, normal 0-degree phase-shift pattern; B, same as A, except oscilloscope has distortion in vertical amplifier, caused possibly by overloading; C, same as A, except signal has second-harmonic distortion; D, sinoidal signal with superimposed noise, originating either from outside the instrument or from noisy tubes within.

3. *A fine, pencil-thin trace.* This is indispensable for critical measurements of inductance, capacitance, dissipation factors, phase shift, and distortion.

4. *Freedom from drifting pattern or microphonics.*

5. *Proper operation of sweep and focus controls.*

6. *Adequate re-trace suppression and linearity of sweep.*

7. *Pattern of ample intensity*, which should be seen clearly in areas of high ambient light.

Routine service includes, in order of performance: (1) check and renewal of vacuum tubes, (2) physical check, (3) test and correction for thin line, (4) power-supply check, (5) sensitivity check, (6) frequency-response check, (7) balance and positioning-control check, (8) sweep-signal frequency check, (9) retrace blanking check, and (10) final service of panel controls for noise. Fig. 38 shows patterns for some common defects. Fig. 39 shows the high-voltage section of an oscilloscope; if the trace will not focus, the trouble is probably caused by change with age of the resistors in the high-voltage string. The frequency response can be checked rapidly by use of a square-wave generator. Fig. 40 shows inadequate retrace suppression; an adjustment capacitor is provided for this correction.

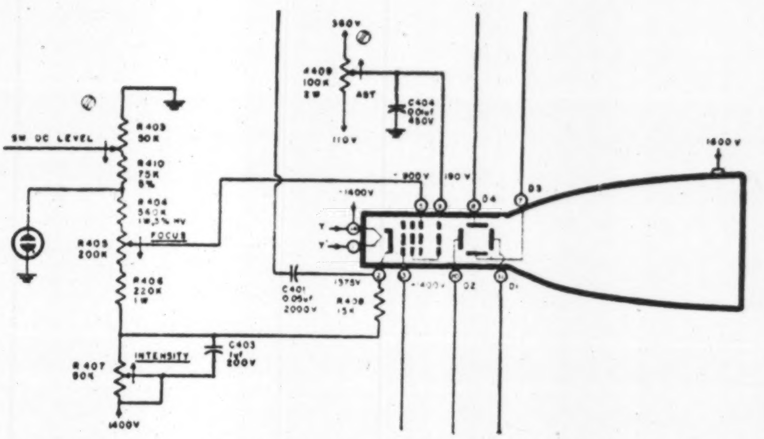


Fig. 39. Electron-gun circuit, including focus and intensity controls, of a typical oscilloscope.

Operating an oscilloscope near a large power transformer, a line-voltage stabilizer or other large electromagnetic field will cause deflection of the amplifiers, fuzziness of pattern, spurious 60-cycle deflection, and abnormal results.

4. Tube Testers

Vacuum tubes can fail for many reasons: coated cathodes lose emission because the cathode coating flakes off; impregnated emitters of filament-type tubes become exhausted with age; air can leak into the tube through defective seals and "poison" the emitting surface; vibration can cause shorts or opens. Commercial tube testers usually provide means for testing for emission, quality, shorts, noise, and gas.

There are several types of tube testers, the two most common being the *emission type* and the *mutual-conductance* type. The former, which is the less expensive, usually connects all grids, screens, and plates together and checks for electron emission only. The latter applies an a-c. signal to the grid of the tube and tests the signal output of the tube.

The RTMA (Radio and Television Manufacturers' Association) proposes to classify tube testers into four classes as follows (Fig. 41):

Class I—*Emission-type tester*, a device incorporating a circuit in which the indication is related primarily to the emission of the tube being tested.

Class II—*Control-emission type tester*, a device incorporating a circuit in which the indication is related jointly to the emission and to the control characteristics of the tube being tested.

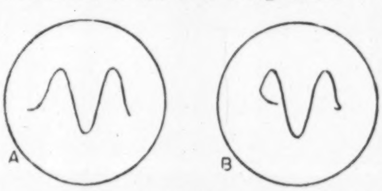


Fig. 40. Examples of inadequate retrace suppression.

Class III—*Control-type tester*, a device incorporating a circuit in which the indication is related primarily to the control characteristics of the tube being tested.

Class IV—*Mutual-conductance-type tester*, an instrument incorporating a circuit which permits quantitative measurement of g_m.

The emission type uses only a-c. potentials and no grid signal. The control-emission type uses a-c. potentials also, but with grid signal. The control type analyzes the signal output, rather than measuring plate current only. The conductance type uses d-c. operating potentials and signal measurements so that the dynamic mutual conductance of the tube ($\Delta I_p / \Delta E_g$) can be measured.

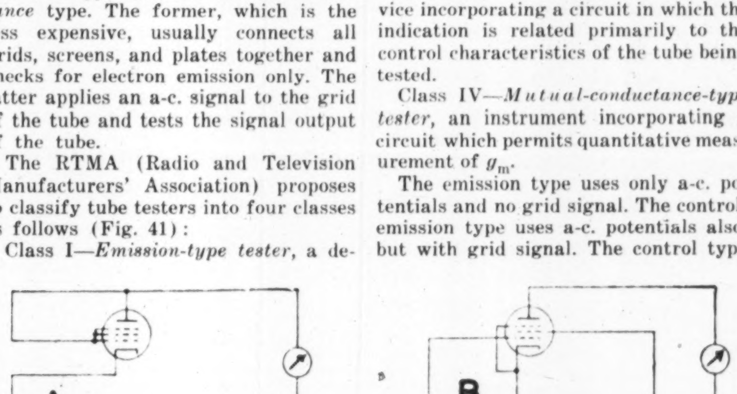


Fig. 41. Proposed classification of tube testers.

5. Frequency Meters (Wavemeters)

Frequency meters are classifiable by *operating principles* as (1) mechanical, (2) electrical, and (3) electronic. All three classes are dealt with in the chapters on Electrical Measurements and Regulation, and on Speed Measurement and Control. There are two types of frequency meters—"EPUT meters" (see Chapter VIII) and wavemeters. There are two types of wavemeters—absorption and heterodyne.

The *absorption* type is simply a resonant tank with a method for indicating the current in the tank. When the resonant circuit is brought near an oscillator, oscillation is induced in the tank if the tank is tuned to the frequency of the oscillator. The current in the tank can be indicated by a neon glow lamp (for high-power measurements) or a rectifier-type p-m. m-c. movement. The advantages of absorption-type wavemeters are (1) simplicity and (2) they oscillate only at their fundamental frequency; for this reason they are used commonly to check if a transmitter is operating on the correct multiple of its oscillator frequency. The disadvantage of absorption-type wavemeters is that they detune the oscillator when coupled to it. Hence they cannot be used for precise frequency measurements.

Absorption-type wavemeters are available at all radio frequencies. Parallel-resonant tanks are used at low, medium, and high radio frequencies. Butterfly tanks are used in the VHF band. Tuned cavities are used in UHF and SHF bands.

The *heterodyne* type of wavemeter uses an accurately calibrated oscillator to heterodyne against the unknown; a zero beat frequency is produced when the two oscillations are at the same frequency. Precautions must be observed when using heterodyne-type frequency measurements to assure that measurements are not being made with harmonics (rather than the desired fundamental frequency) of the calibrated oscillator. Any secondary frequency standard (including WWV transmissions) can be used in this manner to measure and to adjust the frequency of transmitters and receivers.

6. Field-intensity Meters

A field-intensity meter is essentially a portable radio receiver with a method for indicating the strength of a received signal. When used with a directive antenna, such as a loop antenna, they can be used to locate interfering signals, check field patterns, etc.

Acknowledgement

Figs. 7, 9, 10, 11, and 38 are by courtesy of Jay Dobrin, Western Scientific Co., San Carlos, Calif.

Waterman POCKETSCOPE

The Pocket-Size Oscilloscope

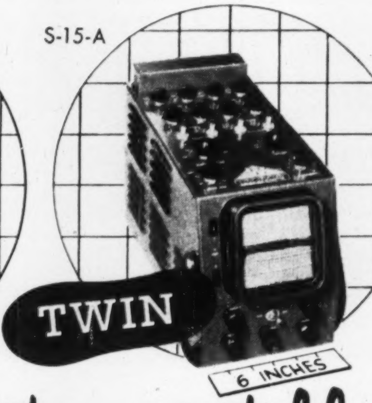
S-14-A

HIGH
6 INCHES

S-14-B

WIDE
6 INCHES

S-15-A



...light...compact...accurate...portable

Featuring small size, light weight and outstanding performance the HIGH, WIDE and TWIN POCKETSCOPES have become the "triple threat" of the oscilloscope field. Their incomparable versatility, reliability and accuracy have skyrocketed this team of truly portable instruments into unparalleled demand. Each oscilloscope features DC coupled amplifiers in both vertical and horizontal channels.

HIGH

The S-14-A HI-GAIN POCKETSCOPE provides the optimum in oscilloscope flexibility for analysis of low-level electrical impulses. Extremely light weight (12¾ lbs.), compact in size (12 x 5¾ x 7 in.), dependable and accurate in performance. Vertical and horizontal channels: 10mv rms/inch with response within 2DB from DC to 200 KC and pulse rise of 1.8 μs . . . non-frequency discriminating attenuators and gain controls with internal calibration of trace amplitude . . . repetitive or trigger time base with linearization from ½ cycle to 50 KC with ± sync or trigger.

WIDE

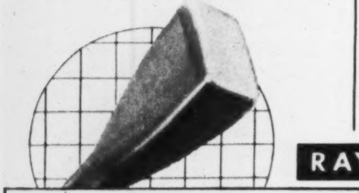
The S-14-B WIDE BAND POCKETSCOPE is ideal for investigations of transient signals, DC signals, aperiodic pulses or recurrent waveforms. Vertical channel: 50 mv rms/in. within —2DB from DC to 700 KC . . . pulse rise time of 0.35 μs. Horizontal channel: 0.15v rms/in. within —2DB from DC to 200 KC . . . pulse rise of 1.8 μs. Attenuators and gain controls are non-frequency discriminating . . . trace amplitude calibration . . . repetitive or triggered time base from ½ cycle to 50 KC . . . ± sync or trigger . . . trace expansion, filter graph screen and many other features . . . 14 lbs. . . . 12 x 6 x 7 inches.

TWIN

The S-15-A POCKETSCOPE is a portable, twin tube, high sensitivity oscilloscope with two independent vertical as well as horizontal channels. It is indispensable for investigation of electronic circuits in industry, school and laboratory. Vertical channels 10 mv rms/in. with response within—2DB from DC to 200 KC and pulse rise time of 1.8 μs . . . horizontal channels 1v rms/in. within —2DB from DC to 150 KC . . . non-frequency discriminating controls . . . internal signal amplitude calibration . . . linear time base from ½ cycle to 50 KC, triggered or repetitive, for both horizontal channels.

S-11-A

The S-11-A INDUSTRIAL POCKETSCOPE is a small, compact (5x7x11 inches), and lightweight (8¾ lbs.) instrument for observing electrical circuit phenomena. The flexibility of the POCKETSCOPE permits its use for AC measurements as well as for DC. The vertical and horizontal amplifiers are capable of reproducing within —2DB from DC to 200 KC with a sensitivity of 0.1v rms/in. . . . repetitive time base from 3 cycles to 50 KC continuously variable throughout its range . . . variations of input impedance, line voltage or controls do not "bounce" the signal—the scope stabilizes immediately.



RAYONIC CATHODE RAY TUBES BY WATERMAN

TUBE	PHYSICAL DATA		STATIC VOLTAGE		DEFLECTION*		LIGHT OUTPUT**
	FACE	LENGTH	A3	A2	VERT	HOR	
3JP1	3"	10"	3000	1500	111	150	352
3MP1	3"	8"		750	99	104	33
3RP1	3"	9.12"		1000	61	86	44
3SP1	1.5x3"	9.12"		1000	61	86	44
3XP1	1.5x3"	8.875"		2000	33	80	218

The basic properties of the cathode ray tube that concern the designer or the user are: deflection sensitivity, unit line brightness, line width, static voltage requirements and physical size. A comparison between cathode ray tubes manufactured by Waterman Products Company is shown in the table adjoining. These tubes are available in P1, P2, P7 and P11 phosphors. 3JP1, 3JP7, 3SP1 and 3XP1 are available as JAN tubes.

Write for your complimentary copy of "POCKETSCOOP" • Official Waterman publication.

For more information circle **103** on inquiry card.

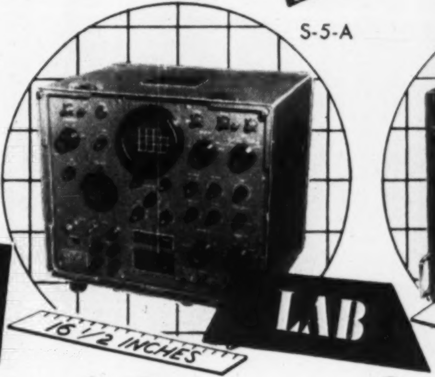
PULSESCOPE by Waterman

The Oscilloscope that Portrays the Pulse

S-6-A

BROAD
6 3/4 INCHES

S-5-A



S-4-C

SAR
9 1/8 INCHES

Classic Examples of Precision Engineering...

The PULSESCOPES are cathode ray tube oscilloscopes that portray the attributes of the pulse: shape, amplitude, duration and time displacement. All PULSESCOPES have internally generated markers with the basic difference that in the SAR PULSESCOPE the markers initiate the sweep while in the others the sweep starts the markers.

BROAD

The S-6-A BROAD BAND Scope is a PULSESCOPE in performance, POCKETSCOPE in size. The instrument measures DC as well as AC signals. Unique DC calibration methods permit rapid measurements of either positive or negative, AC or DC signals. Vertical amplifier sensitivity of 0.2v rms/inch, and response to 5 mc within 3DB . . . pulse rise time of 0.1 μs . . . internal markers from 1 to 1000 μs . . . repetitive or trigger sweep from 5 cycles to 500 KC with 5X sweep expansion . . . sweep, marker and DC calibrating voltage available externally. Size 8½ x 6¾ x 13¾ in. Weight 22 lbs. Operates from 50 to 400 cycles at 115 volts AC.

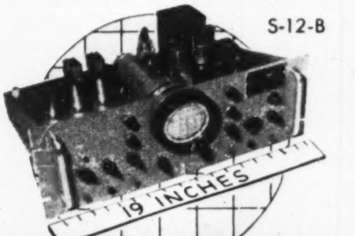
LAB

The S-5-A LAB PULSESCOPE is a JANized (Gov't Model No. OS-26) portable, AC, wide band-pass, laboratory oscilloscope ideal for pulse as well as general purpose measurements. Internal delay of 0.55 μs permits observation of pulse leading edge. Includes precision amplitude calibration, 10X sweep expansion, internal trace intensity time markers, internal trigger generators and many other features. Video amplifier 0.1v p to p/inch . . . pulse rise time of .035 μs or response to 11 mc. 1.25 to 125,000 μs triggered or repetitive sweep . . . internally generated markers from 0.2 to 500 μs . . . trigger generator from 50 to 5000 pps. for internal and external triggering. Operates from 50 to 400 cycles at 115 volts AC.

SAR

The S-4-C SAR PULSESCOPE is a JANized (Gov't Model No. OS-4) portable instrument (31.5 lbs.) for precision pulse measurements for radar, TV and all electronic measurements. Portrays all attributes of the pulse . . . internal crystal controlled markers of 10 and 50 μs available for self-calibration . . . in R operation a small segment of the A sweep is expandable for detailed observation with a direct-reading calibrated dial accurate to 0.1%. Video amplifier band-pass up to 11 mc . . . optional video delay 0.55 μs . . . pulse rise and fall time better than 0.07 μs . . . R pedestal (sweep) 2.4 to 24 μs . . . video sensitivity of 0.5v. p to p/inch. Easily convertible from μs to yards. Operates from 50 to 400 cycles at 115 volts AC.

S-12-B



RAKSCOPE

Because the panel is only 7″ high and fits any standard rack, the S-12-B RAKSCOPE admirably fills the need for a small oscilloscope of wide versatility. With all the features of the S-11-A POCKETSCOPE, the RAKSCOPE is JANized (Gov't Model No. OS-11), and has many additional advantages; the sweep, from 5 cycles to 50 KC, is either repetitive or triggered . . . vertical and horizontal amplifiers are 50 mv rms/inch with band-pass from 0 to 200 KC . . . special phasing circuitry for frequency comparison.

WATERMAN PRODUCTS CO., INC.

WATERMAN PRODUCTS

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CABLE ADDRESS, POKETSCOPE, PHILA.

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STANDARD SIGNAL GENERATOR MODEL 65-B

FREQUENCY RANGE	OUTPUT RANGE	MODULATION
75 Kc.—30 Mc.	0.1 microvolt to 2.2 volts	AM. 0 to 100% 400 cycles or 1000 cycles External mod., 50-10,000 cycles

STANDARD SIGNAL GENERATOR MODEL 78

FREQUENCY RANGE	OUTPUT RANGE	MODULATION
15-25 Mc.; 195-225 Mc. 15-25 Mc.; 90-125 Mc. Other ranges on order	1 to 100,000 microvolts	AM. 8200-400 cycles 625—400 cycles Fixed at approximately 30%

STANDARD SIGNAL GENERATOR MODEL 78-FM

FREQUENCY RANGE	OUTPUT RANGE	MODULATION
86 Mc.—108 Mc.	1 to 100,000 microvolts	Deviation 0-300 Kc. 2 ranges FM. 400 and 8200 cycles External mod. to 15 Kc.

STANDARD SIGNAL GENERATOR MODEL 80

FREQUENCY RANGE	OUTPUT RANGE	MODULATION
2 Mc.—400 Mc.	0.1 to 100,000 microvolts	AM. 0 to 30% 400 cycles or 1000 cycles External mod., 50-10,000 cycles

STANDARD SIGNAL GENERATOR MODEL 82

FREQUENCY RANGE	OUTPUT RANGE	MODULATION
20 cycles to 200 Kc. 80 Kc. to 50 Mc.	0-50 volts 0.1 microvolt to 1 volt	Continuously variable 0-50% from 20 cycles to 20 Kc.

STANDARD SIGNAL GENERATOR MODEL 84

FREQUENCY RANGE	OUTPUT RANGE	MODULATION
300 Mc.—1000 Mc.	0.1 to 100,000 microvolts	AM. 0 to 30%, 400, 1000, or 2500 cycles. Internal pulse modulator. External mod., 50-30,000 cycles.

STANDARD SIGNAL GENERATOR MODEL 84-TV

FREQUENCY RANGE	OUTPUT RANGE	MODULATION
300 Mc. to 1000 Mc.	Continuously variable from 0.1 microvolt to 1.0 volt	Continuously variable 0 to 30% External modulation 20 to 20,000 cycles.

STANDARD SIGNAL GENERATOR MODEL 90

FREQUENCY RANGE	OUTPUT RANGE	MODULATION
20 Mc.—250 Mc.	0.3 microvolt to 0.1 volt	Continuously variable, 0 to 100% Sinusoidal modulation 30 cycles 5 mc. Composite TV modulation.

PULSE GENERATOR MODEL 79-B

FREQUENCY RANGE	PULSE WIDTH	OUTPUT
60 to 100,000 cycles	Continuously variable from 0.5 to 40 microseconds	Approx. 150 v. positive with respect to ground. "Sync Output" 35 v. positive with respect to ground.

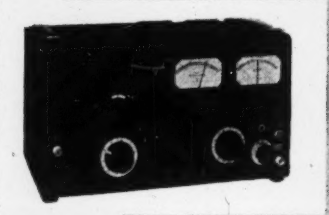
SQUARE WAVE GENERATOR MODEL 71

FREQUENCY RANGE	WAVE SHAPE	OUTPUT
Continuously variable 6 to 100,000 cycles	Rise time less than 0.2 microseconds with negligible overshoot	Step attenuator 75, 50, 25, 15, 10, 5 peak volts fixed and 0 to 2.5 volts continuously variable

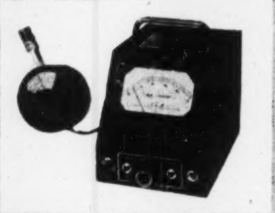
VACUUM TUBE VOLTMETERS

MODEL 62		
VOLTAGE RANGE	**FREQUENCY RANGE**	**INPUT IMPEDANCE**
0-1, 0-3, 0-30 and 0-100 volts AC or DC	30 cycles to over 150 Mc.	Approximately 7 mmfd
MODEL 67		
VOLTAGE RANGE	**FREQUENCY RANGE**	**INPUT IMPEDANCE**
.0005 to 300 volts peak-to-peak	5 to 100,000 sine-wave cycles per second	1 megohm shunted by 30 mmfd.

CRYSTAL CALIBRATOR MODEL 111



STANDARD SIGNAL GENERATOR MODEL 80



MEGACYCLE METER MODEL 59

U.H.F. FIELD STRENGTH METER MODEL 58

FREQUENCY RANGE	INPUT VOLTAGE RANGE
15 Mc. to 150 Mc.	1 to 100,000 microvolts in antenna. 1 to 100 microvolts on semi-logarithmic output meter, balanced resistance attenuator with ratios of 10, 100 and 1000 ahead of all tubes.

INTERMODULATION METER MODEL 31

INTERMODULATION RANGE	FREQUENCIES (CYCLES)	ANALYZER INPUT VOLTAGES
3%, 10% and 30% Full scale	LF 60 cps HF 3000 cps	Full scale ranges of 3, 10, 30 volts RMS

MEGACYCLE METERS MODELS 59LF—59—59UHF

FREQUENCY RANGE	FREQUENCY ACCURACY	MODULATION
0.1 Mc. to 4.5 Mc. 2.2 Mc. to 400 Mc. 430 Mc. to 940 Mc.	Within ±2%	CW or 120 cycles fixed at approximately 30%. Provision for external modulation

CRYSTAL CALIBRATORS

MODEL 111		
FREQUENCY RANGE	**FREQUENCY ACCURACY**	**HARMONIC RANGE**
250 Kc.—1000 Mc.	0.002%	.25 Mc. Oscillator .25-450 Mc. 1 Mc. Oscillator 1-600 Mc. 10 Mc. Oscillator 10-1000 Mc.
MODEL 111-B		
FREQUENCY RANGE	**FREQUENCY ACCURACY**	**HARMONIC RANGE**
100 Kc.—1000 Mc.	0.002%	.1 Mc. Oscillator .1 — 450 Mc. 1 Mc. Oscillator 1 — 600 Mc. 10 Mc. Oscillator 10 — 1000 Mc.

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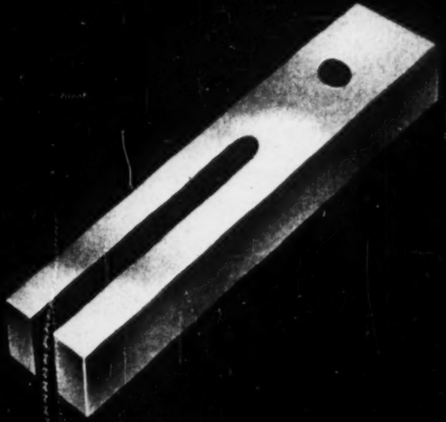

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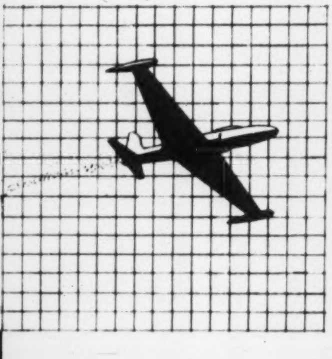

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- ***PRECISION WIRE-WOUND POTENTIOMETERS***
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Model M10-3000

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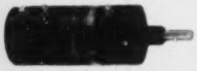


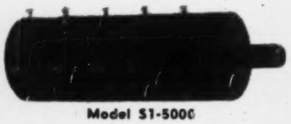
Model M10-2000

LEFT: TEN TURN POTS

Data	M10-1000	M10-2000	M10-3000
Housing dia.	1"	¾"	1⅞"
Resist. Range	100 ohm to 150K	100 ohm to 75K	1 ohm to 500K
Std. Lin. Tol.	±0.5%	±0.5%	±0.5%
Wattage Rating	3 W	2 W	5 W

RIGHT: SINGLE TURN POTS

Data	S1 3000	S1 5000
Housing dia.	2"	1"
Resist. Range	5 ohm to 100 K	5 ohm to 50 K
Std. Lin. Tol.	±0.5%	±2%
Wattage Rating	4 W	1.5 W



Model S1-5000

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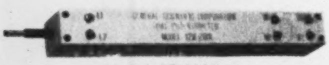

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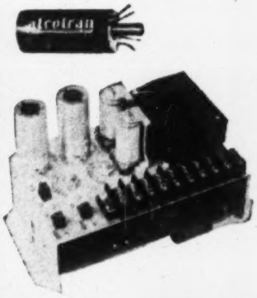
repeats within .0001"

actuating force .01 gram

no overtravel problem



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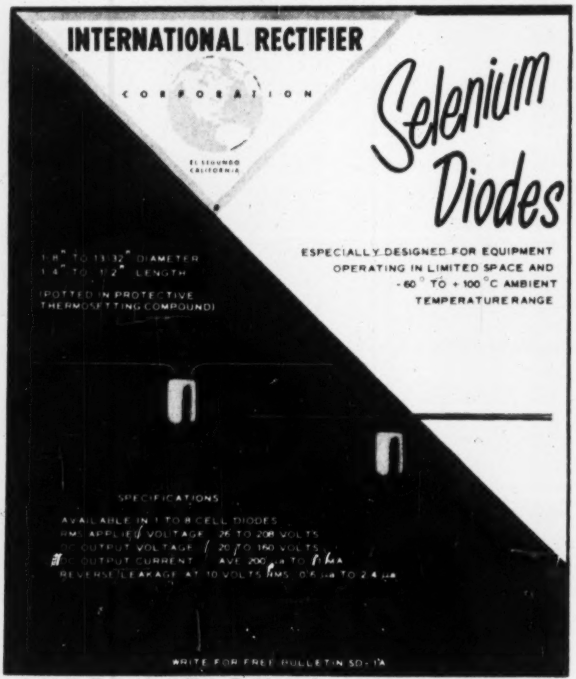

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NM-30A 20mc to 400mc

Commercial Equivalent of AN/URM-47. Frequency range includes FM and TV bands.

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NM-10A 14kc to 250kc

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Very low frequencies

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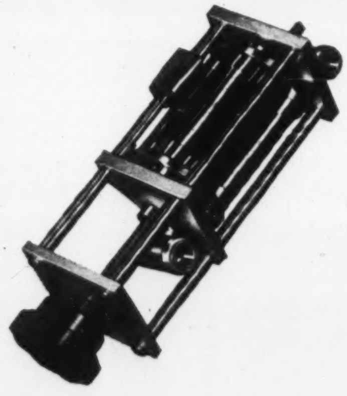
Commercial Equivalent of AN/PRM-1A Self-contained batteries. A. C. supply optional. Includes standard broadcast band, radio range, WWV, and communications frequencies. Has BFO.



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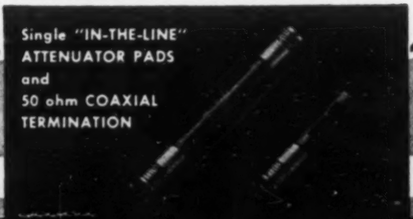
TURRET ATTENUATOR featuring "PULL-TURN-PUSH" action

FREQUENCY RANGE: dc to 3000 mc.
CHARACTERISTIC IMPEDANCE: 50 ohms
CONNECTORS: Type "N" Coaxial female fittings each end
AVAILABLE ATTENUATION: Any value from .1 db to 60 db
VSWR: <1.2, dc to 3000 mc., for all values from 10 to 60 db
<1.5, dc to 3000 mc., for values from .1 to 9 db
ACCURACY: ±0.5 db
POWER RATING: One watt sine wave power dissipation

Send for free bulletin entitled "Measurement of RF Attenuation"

Inquiries invited concerning pads or turrets with different connector styles



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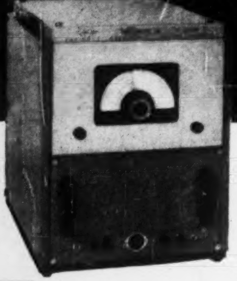
NEW VECTRON VFS 250
Variable Frequency Power Supply



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Output Power at 100 to 130 V	250VA continuous 300VA intermittent
Output Frequency	45-2,000 cycles
Output Voltage	0-130 Volts
Output Regulation zero to full load	± 1% to 1,000 cycles ± 2% to 2,000 cycles
Line Regulation at 250VA	± 1% maximum change for 105-125V input

Flexible, can be supplied with limited frequency ranges 45-75 cycles and/or 320-480 cycles, with stabilized single frequency tuning fork or single range to cover entire frequency spread as required. An external frequency source may be used. Can be furnished with complete frequency programming equipment built in for fixed or variable cycle. Metering of output voltage, current and/or frequency can be included.

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STRAIGHT (Batch) COUNTER
TACHOMETER

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DS-6100 FREQUENCY COUNTER

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20 to 100,000 CPS
GATE TIME
1 second (.1 and 10 sec. available)
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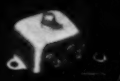

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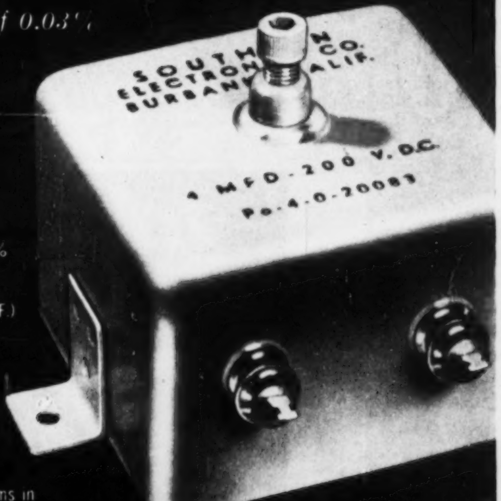

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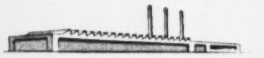

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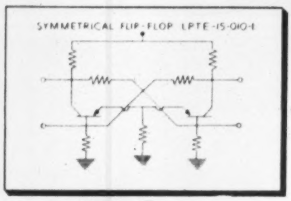

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CHAPTER XII

FIDELITY OF RESPONSE

(Dynamic Properties of Systems and Components)

By M. F. BEHAR

1. ARBITRARY DIVIDING LINE

To the instrument user, the dividing line between statics and dynamics is indefinite—and rightly so. In discussing the STATIC measuring properties* it was necessary to touch upon some dynamic effects which influence static accuracy. These effects are not ordinarily thought of as dynamic. For example, frequency, wave-form and power factor influence the accuracy of an a-c. indicating wattmeter; but the user of this indicator instinctively puts these three conditions in the same category as temperature, magnetic fields, dust, moisture and vibrations—all eight being common enemies of "steady-state" accuracy.

This same user instinctively associates the RECORDING of engine cylinder-wall temperature FLUCTUATIONS with tiny thermocouples rather than with mercury-in-steel bulbs.

The user makes this distinction between accuracy (of "ordinary" measurements) and FIDELITY of recording, whether he be a novice at mathematics or a professional engineer with training in heat transfer, network theory, etc., followed by years of practice. Both the novice and the expert know that if a d-c. recording voltmeter is connected to an a-c. line, its pen will tremble almost imperceptibly at zero. Both know that if the bulb of a mercury-system recorder is plunged alternately every second in ice-water and boiling water, this recorder's pen will not travel between 32 and 212, but will eventually hover about the half-way point of 122.

Such is the arbitrary demarcation. This Chapter continues to deal with the ideal of Accuracy but in terms of dynamic measuring properties collectively known as Fidelity of Response.

2. TWO CHIEF INGREDIENTS OF FIDELITY

Since Accuracy is the resultant of all measuring properties, Fidelity is sometimes viewed as only one of the active measuring properties. Another view is that the steady-state accuracy of a measuring system in equilibrium is only one of the measuring properties that go to make a high-fidelity dynamic measuring system. The choice depends on the scope of the particular functional analysis being made.

It is assumed, throughout this Chapter, that the systems dealt with possess ideal STATIC Accuracy.

(This means, among other cases, that if the Measurable is a.c. and the system an a-c. ammeter, the reading always equals the True Value of the Measurable: the rms. current—not the instantaneous current—whenever the Measurable is steady or changing "very slowly.")

It is assumed also that the Measurable has been steady before the moment it begins to change suddenly—long enough for the system to have come to equilibrium. In other words, at the instant that a sudden change begins (at t_0 or zero time) the Indication—the output signal in the case of a "blind" system—equals the True Value.

Fidelity of Response is made up of many ingredients: two essential, all others refinements.

The two basic ingredients are:

(1) Relatively low thermal, electrical, hydraulic, pneumatic or other resistance—so that a necessary flow (of energy or of matter) will not be slowed down. There is no precise name for this dynamic property. "Low resistance" alone does not suffice because "low capacitANCE" (electrical), "low capacitY (volumetric), and other well-known concepts would have to be used with it. The single word "speed" and the expression "speed of response" are frequently used (but speed of response depends also on Ingredient No. 2). In discussing temperature-measuring systems alone, "Thermometric Lag" identifies the subject; in discussing electrical systems, the symbols *RC* tell the story. For the sake of convenience, it has been customary in Instrumentation writings to refer to the shape of the curve of the *simplest* (first-order) response of this kind; and to call this property THE SIMPLE (or PURE) EXPONENTIAL RESPONSE.

(2) The second essential property is a relatively low Inertance: a relatively small mass to be displaced mechanically, a relatively low thermal inertia, etc. Again, there is no single precise term for this simplified concept. (The nearest to a precise name is "the required response of a high-speed recorder.") This property *alone* is often called "Fidelity" or "Dynamic Response" although these broad terms imply the resultant of all dynamic properties. In Instrumentation it has also been called the Kinetic Behavior to identify it with MOTION. Here, for the sake of convenience, it may be identified by the three physical elements Mass, Spring and Damping Means—and it may be called THE MSD RESPONSE.

Ideal Fidelity is made up of an ideal Exponential plus an ideal MSD Response. Both ideals are zero: total absence of a "curve," hence instantaneous obedience to the command. The encouraging conclusion is that if the instrument user strives for a good Simple Exponential and a good Simple MSD Response, he will get High Fidelity—because, in about 95% of actual cases, the influence of the other dynamic properties of his components and systems will be negligible.

(About 95% refers to measuring systems, to transmission systems, and to complete indicators, recorders, etc., but not necessarily to all classes of closed-loop dynamic systems. In some of these, a "minor" component may have a queer transfer function challenging skilled mathematicians and playing havoc with the performance of the whole system.)

3. THE EXPONENTIAL

(a) *Characteristic Time*

Consider a standpipe 100 feet tall, initially full of water. At time equal zero, a leak in the bottom plate is suddenly unplugged. A precision level gage, and a stop-watch, permit measuring the falling level every minute, hence the average RATE of fall during each minute. The first few observations apparently show a uniform rate of fall which, if maintained, will drain the standpipe in exactly 100 hours. The leak, however, is an orifice so shaped that the flow-rate through it is exactly proportional to the head of water. The RATE-OF-FALL of level does not remain constant: it decreases as the level falls; it began to decrease from the instant t_0 but so gradually that the first few minutes' observations could not detect the change of rate. At the end of exactly 100 hours, the level is measured. It is found to be 36.788 feet. Instead of the standpipe being completely drained, it is only 63.212% drained. The fraction drained is 1/2.7183. (The number 2.718... is e, the base of natural logarithms.)

Second example: A capacitor discharges through a resistor in a dry-air chamber (no leakage). The initial rate is such that, if maintained, the stored electricity will all have been discharged at the end of 1000 seconds. At $t=1000$, it is found that the capacitor is only 63.2% discharged.

Third example (see left-hand drawing of Fig. 4-7): Into an insulated 6000-gal. tank full of water at x deg., water at $x+100$ deg. is fed at the CONSTANT rate of 10 gps. beginning at t_0. Thus, after 6 seconds, the mixture temperature will be $x+1$ deg. and, from this INITIAL SLOPE, it seems that the tank-content's temperature will be $x+100$ deg. at the end of 600 sec. At the end of that time the mixture temperature is $x+63.2$ deg.

Fourth example: In 1701, Newton measured furnace temperature inferentially by noting the exact time when a cannon-ball was suddenly withdrawn from the furnace, waiting until it cooled enough to use thermometers (actually surface thermoscopes: "particles of fusible bodies"), then plotting this part of the cooling curve and finally extrapolating back. See Fig. 4-1.

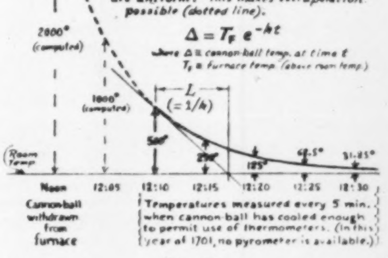


Fig. 4-1

All four examples have in common the Simple Exponential response to a sudden change. Only the fourth one involves a clear-cut and obvious sudden change in a Measurable: the sudden change from furnace temperature to room temperature with Newton's famous cannon-ball as the "primary measuring element."

---

*Part 3 of Chapter I of the first (1951) addition of this book.

Fig. 4-1 gives one of the ways in which an exponential curve may be written. It is an abridged equation in terms of delta, the REMAINING DIFFERENCE. Its essential is the negative power (exponent) of e, which represents the physical law. (This law is known as "logarithmic decay" in nucleonics, biology and other fields). The physical meaning of the minus sign is: the longer the time, the less the value of delta: of the remaining difference.

For generality, the linear differential equation of the simple exponential response may be written in terms of:

(1) A sudden change, or step command, or step input, which is the difference between the previous true value T_P, and the new true value T_N of the measurable. This step input is:

$$T_I = (T_N \pm T_P),$$

the subscript I meaning input.

(2) The instantaneous value (at time t) of the indication or signal T_O, the subscript O meaning output.

(3) A constant k, which determines the slope.

(4) A constant L $(=1/k)$ which is the reciprocal of k.

In these terms, the fundamental equation is:

$$\frac{dT_O}{dt} = k(T_O \pm T_I)$$

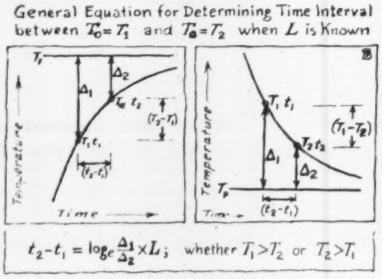
which may also be written

$$L\frac{dT_O}{dt} = (T_O \pm T_I)$$

in which L has the dimension of time, for it is the time for T_O to become $1/e$ of T_I. This is the CHARACTERISTIC TIME—perhaps the most important of all dynamic properties of measuring elements and systems. It is symbolized k in mathematics and general physics. In thermal applications (where T and t mean temperature and time) it is known as the Lag Coefficient or Thermometric Lag L; in electricity it is widely known as the "time constant" and is often symbolized by the Greek letter tau.

The Characteristic Time is not always an intrinsic property of an element or system. Sometimes it depends mostly on extrinsic conditions. For example, the lag L of the primary element ("bulb") of a thermal system may be several seconds in rapidly-circulated water and several minutes in stagnant air. In electrical components the characteristic times are likewise altered by extrinsic conditions, though not as much. This inconstancy of what is called a "constant" in many writings should be borne in mind—especially in automatic-control systems where a variable characteristic time becomes a variable phase difference which, in extreme cases, makes previously-stabilized systems oscillate wildly.

In some occupational fields, exponential characteristics are given in terms of the "half-life," or "difference-halving period," or "half-period," which is $L \times \log_e 2$, or approximately two-thirds of the characteristic time.


General Equation for Determining Time Interval between $T_O = T_1$ and $T_O = T_2$ when L is Known

$$t_2 - t_1 = \log_e \frac{\Delta_1}{\Delta_2} \times L; \quad \text{whether } T_1 > T_2 \text{ or } T_2 > T_1$$

Fig. 4-2

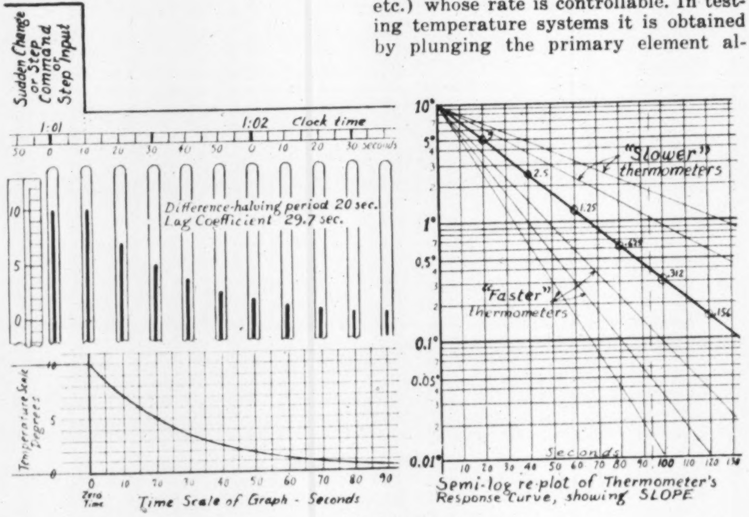
An exponential plots as a straight line on a graph with logarithmic ordinates and linear time abscissa (Fig. 4-3), which fact permits comparing the "speeds" of different systems or components and—more important—detecting at a glance any departure from the simple law.

(b) Pure Exponential: Linear-change Command

Sudden-change commands are the simplest to give as examples; but actual systems are subjected in practice to an infinite variety of commands. The response to a linear-change command is illustrated in Fig. 4-4. Note that the dynamic error INCREASES until it reaches the final value shown by the dotted line. Note also that, at the end of 3 L, the dynamic error is about 80% of its final value which, in the case here illustrated, is 3 degrees. This graph, as printed, is scaled to make 1 cm. equal to 1 degree or 1 second, to facilitate its use by non-mathematical readers.

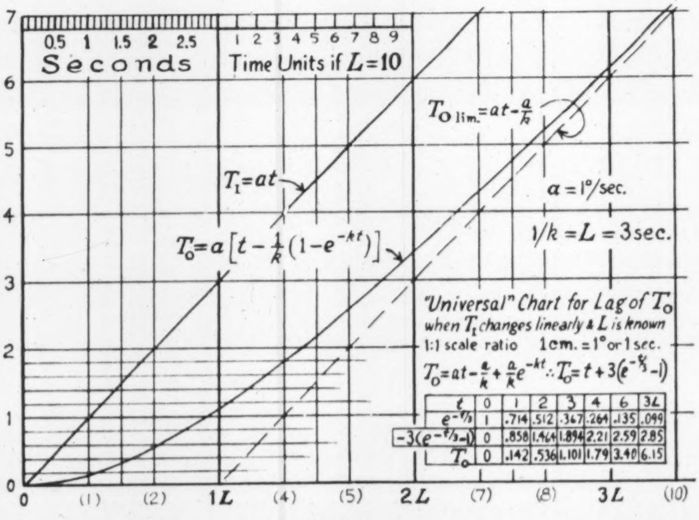
(c) Pure Exponential: Periodic Commands

(1) "Square-wave" Command.—In testing electrical components, this type of input is obtained from a d-c. supply by an automatic cyclic reversing switch (usually non-mechanical: thyratron, etc.) whose rate is controllable. In testing temperature systems it is obtained by plunging the primary element al-



Semi-log re-plot of Thermometer's Response Curve, showing SLOPE

Fig. 4-3



"Universal" Chart for Lag of T_O when T_I changes linearly & L is known

1:1 scale ratio 1cm. = 1° or 1 sec.

$$T_O = at - \frac{a}{k} + \frac{a}{k}e^{-kt} \therefore T_O = t + 3(e^{-t/3} - 1)$$

t	0	1	2	3	4	6	3L
$e^{-t/3}$	1	.714	.512	.367	.264	.135	.099
$-3(e^{-t/3}-1)$	0	.858	1.464	1.894	2.21	2.59	2.85
T_O	0	.142	.536	1.101	1.79	3.40	6.15

Fig. 4-4

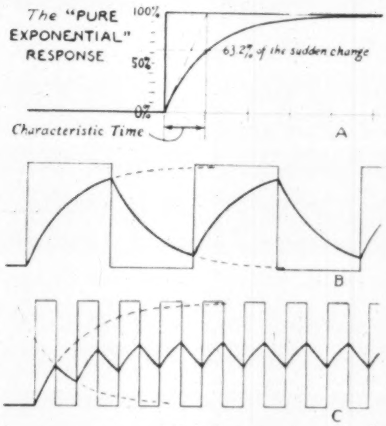


Fig. 4-5

ternately in cold and hot baths, by rotating a sector-disk between a radiant source and the primary element, or by some other test setup.* Fig. 4-5 shows how the output is attenuated increasingly by increasing the frequency of alternations. This is one reason why many electrical components perform best over a given range of frequencies.

(2) Sinoidal Command.—See below, under (*f*).

(*d*) *The "Delayed Start"*

As mentioned under (*a*), a "pure" exponential implies certain ideal properties of materials, etc. Actual materials and actual structures modify the actual responses. An oft-cited thermal example is a fine-wire thermocouple ($L = 0.01$ sec.) in a heavy ceramic protecting tube with a dead-air space: not only will the 63% point be reached in an enormously greater time, but there will be no appreciable thermocouple response until several hundred times the bare-wire characteristic time. Fig. 4-6 shows roughly the effects of structural complexities. A well-known bad effect is that of a thin-wall bulb which starts expanding at once while the relatively large body of mercury "waits for the heat to penetrate it" so that the reading "dips": drops before starting to rise. It is particularly bad in automatic-control systems, for the initial command issued by the measuring element is the exact opposite of what it should be.

(*e*) *The "Delayed End"*

The delayed start is a slow RADIAL heat flow caused by "bulb" structure; the delayed end is a slow LONGITUDINAL heat flow caused by "stem" structure. The delayed start is bad for automatic control; the delayed end does not worsen control but it is exasperating in measurement work. (It is a source of errors of observation whenever the user—through ignorance or impatience—fails to wait long enough.)

Space does not permit detailed discussions of structural effects. Fig. 4-7 brings out the importance of the Unidirectional Property discussed at length

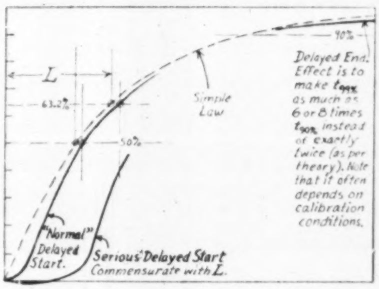


Fig. 4-6

in Part 3 of Chapter I of the first (1951) edition of this book. The four elements at the left, and the four at the right, may be thermal, electrical, hydralic or pneumatic. The cascade at the left is the rare exception: the great majority of actual systems are depicted by the right-hand drawings. The captions should be studied.

Fig. 4-7 shows, by comparison with Fig. 4-5, that a "slow-start" exponential causes a much greater attenuation of a square-wave input than a pure exponential.

(*f*) *Energy-flow Effects*

Apart from structural complexities, there is the hard fact that even elemental components, in actuality, represent resistances, capacitances, etc., though they may be simple homogeneous bodies. Even the simple rod of a rod thermostat—the nearest thing to Newton's cannon-ball—does not exactly obey Newton's law of cooling. It CANNOT obey it by yielding a pure exponential because, at the moment of a sudden change, its axial temperature is still the "previous" temperature. Its AVERAGE temperature, therefore, lags behind the changing surface temperature at all times. The same physical principle holds true for various classes of athermal elements.

Fig. 4-8 gives a thermal example and brings out several aspects of the effect of energy-flow in simple homo-

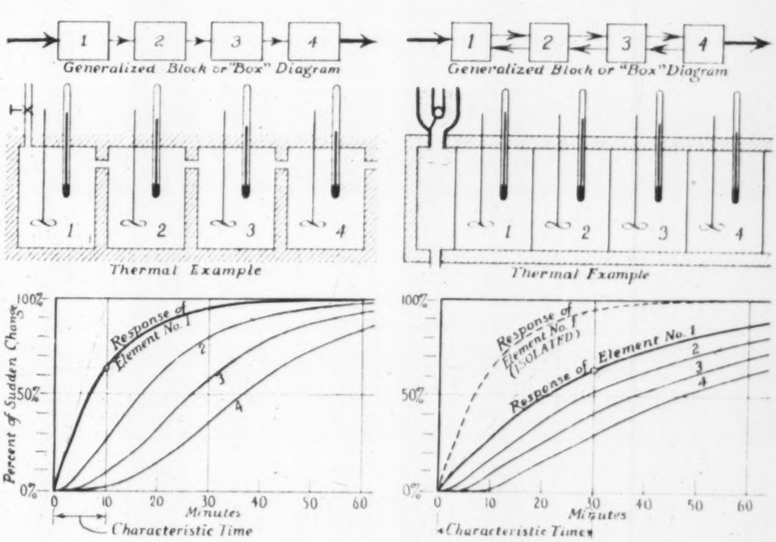


Fig. 4-7. Block diagrams and thermal analogs of two types of four-element systems, representing the majority of actual systems whose response departs from the Pure (first-order) Exponential.

In both analogs, the bodies of fluid in all four compartments are INITIALLY in thermal equilibrium with one another and with the heat source (the "cold" source before zero time).

In both systems, the heat source is suddenly switched on at time equal zero. The initial rates of heat transfer are such that IF each system consisted of only ONE element (No. 1), the initial slopes of the temperature rise in both these isolated undirectional No. 1 elements would be equal.

UNIDIRECTIONAL ANALOG

In this cascade system the response of the first element is not affected by the succeeding elements. At zero time, fluid at a different temperature from that of the fluid in the system starts flowing into the first compartment. The influx rate is such that the compartment (if initially empty) would be filled in 10 minutes. The mixing is perfect; only perfectly-mixed fluid flows from each compartment to the next—at a rate equal to the influx; therefore the temperature rise is exponential.

The response of No. 4 is much like that of the center of a sphere of low thermal diffusivity, whose surface is subjected to a sudden temperature change.

REFLEX-ACTION ANALOG

In this system the elements react on one another. A selector valve admits either hot or cold water to the "command" compartment at the left of No. 1. If the thin partition between compartments 1 and 2 were replaced by ideal insulation, the characteristic time of No. 1 would be 10 minutes. With thin partitions as shown, the compartments are in thermal communication. Note the threefold lengthening of the characteristic time of No. 1 and the serious "delayed starts" of the others.

The shapes of the responses of elements 1, 2, 3 and 4 resemble the responses of thermocouples embedded in a wall heated on one side only.

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*See "The Primary-element Response," *Instruments*, Aug. 1948, pages 691-698.

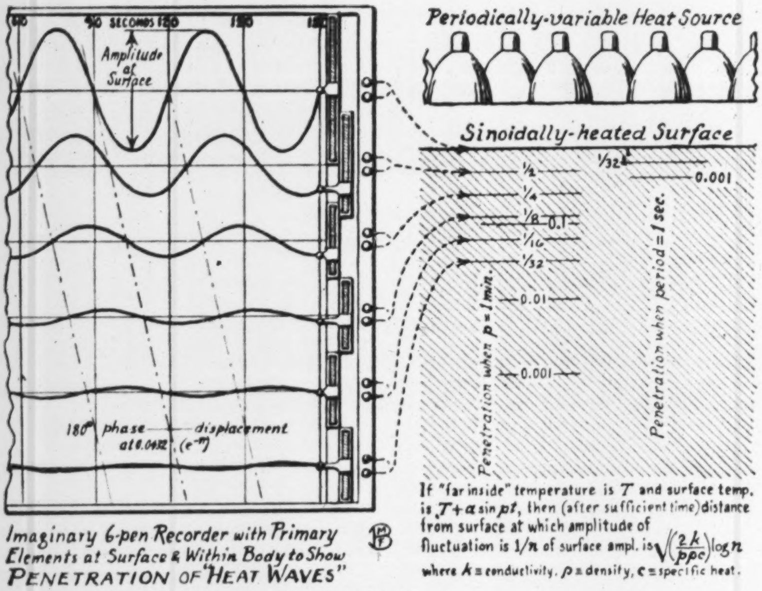

90
SECONDS 120
120
Amplitude at Surface
180° phase displacement at 0.0412 ($e^{-\pi}$)
Imaginary 6-pen Recorder with Primary Elements at Surface & Within Body to Show PENETRATION OF "HEAT WAVES"
Periodically-variable Heat Source
Sinoidally-heated Surface
1/2
1/4
1/8
0.1
1/16
1/32
0.01
0.001
1/32
0.001
Penetration when p = 1 min.
Penetration when period = 1 sec.
If "far inside" temperature is T and surface temp. is T + a sin pt, then (after sufficient time) distance from surface at which amplitude of fluctuation is 1/n of surface ampl. is $\sqrt{\left(\frac{2k}{p\rho c}\right)}\log n$
where k = conductivity, ρ = density, c = specific heat.

Fig. 4-8

geneous bodies. To show the thermal-electrical analogy, the relation of attenuation and phase lag has purposely been drawn on the "record." The study of Fig. 4-8, like that of Fig. 4-7, will reward readers interested in "thermometric speed" or *diffusivity* (see Ch. I, Part 1, Sec. 3).

4. THE MSD RESPONSE

(a) The Physical Elements

Since the theoretical ideal of instantaneous response is unattainable, the practical ideal is that, after a sudden change in the value of the Measurable, the measuring system's output signal should, with least possible delay, exactly equal the new value. In referring to a measuring system with visible parts, "the pointer or pen should come to rest with least possible overshoot, error and delay."

Fig. 4-9 illustrates what is often called the fundamental problem of the galvanometer or of the high-speed recorder. It brings out the relation of the three factors, *M*, *S* and *D*, to the kinetic behavior of a system: The springs are assumed to be ideal tension-compression springs, whose force is exactly proportional to the displacement from equilibrium position. This displacement, denoted by the symbol *x*, is the position of the mass with respect to the frame. (When the frame is stationary in space, it is the position of the mass in space.) The system shown at A will have a much longer natural period of oscillation (a much lower natural frequency) than the B system. Both A and B would oscillate "forever" if it were not for friction. The C system is provided with viscous damping (resistance proportional to speed). The valve symbol (X) illustrates ADJUSTABILITY of damping—extremely important in practice.

Fig. 4-10 visualizes the different kinetic behaviors of MS and MSD systems after the mass has been pushed away from equilibrium and let go—after a STEP INPUT. The fundamental equations of motion are composed of two terms for MS and three terms for MSD. The term for the spring is the simplest. It is Kx, the constant K (stiffness in units of force) multiplied by x which is the distance away from equilibrium position in space.

Damping term: viscous damping (also in units of force) is proportional to speed; speed is rate of change or first derivative of position x; therefore the expression is $D \times (dx/dt)$.

Mass term: at any instant, the opposing force (expressed in the same units as K and D) is proportional to acceleration, which is the rate of change of speed, or the second derivative of the position x; therefore this term is $M \times (d^2x/dt^2)$.

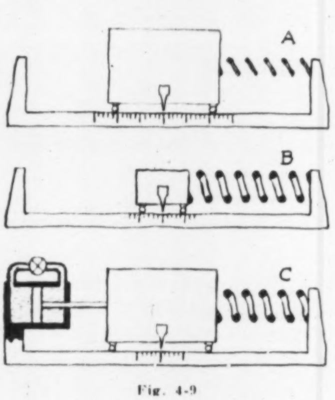


Fig. 4-9

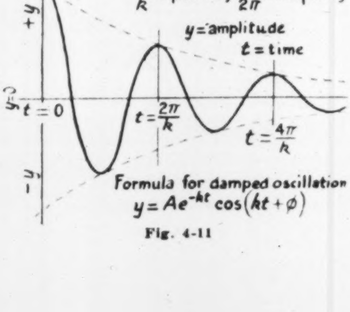


Fig. 4-11

The equation of motion for the *MS* system states that at any instant the *S* term opposes the *M* term, so that their algebraic sum is zero:

$$M\frac{d^2x}{dt^2} + Kx = 0$$

Likewise, the complete equation of motion for the *MSD* system is:

$$M\frac{d^2x}{dt^2} + D\frac{dx}{dt} + Kx = 0$$

The solutions of these equations are explained in numerous textbooks. It suffices, for the moment, to state that they are shown roughly as chart records in Fig. 4-10. The undamped oscillation is a SINOID: a sine or cosine curve. (These are alike except for a 180-degree or $\pi/2$ phase difference.)

In Fig. 4-11 there is given the simplest equation for a damped oscillation.

In the systems pictured in Figs. 4-9 and 4-10 the equilibrium position is mid-scale. A step input consists in suddenly releasing the mass after having pushed it away from zero. But these pictures can also represent measuring systems of any class, if the reader simply imagines an additional element which commands the mass to move from zero to a given scale graduation where equilibrium will be reached. For example, imagine the mass to be of iron and imagine a coil surrounding it: the result is a plunger-type d-c. ammeter. Now, a step input is a sudden change in current: from zero current (natural equilibrium) to a positive or negative value, or from *any* value to *any other* value within the scale range.

(b) The Three Types of Damping

Only true viscous damping is considered here. (In practice, the familiar magnetic damping of electrical instruments comes close to the ideally viscous damping; and it is conveniently adjustable.) Adjustability is desirable because the same system may be used

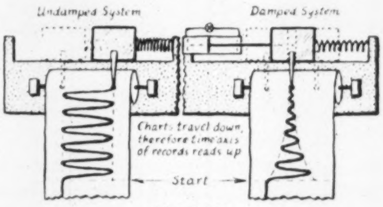

Undamped System
Damped System
Charts travel down, therefore time axis of records reads up
Start

Fig. 4-10

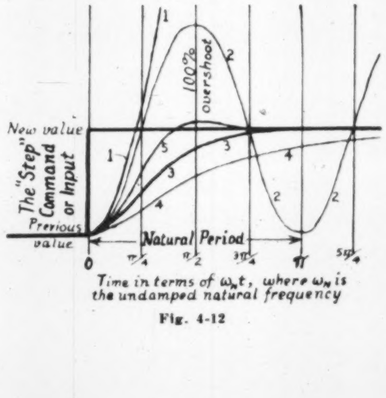


Fig. 4-12

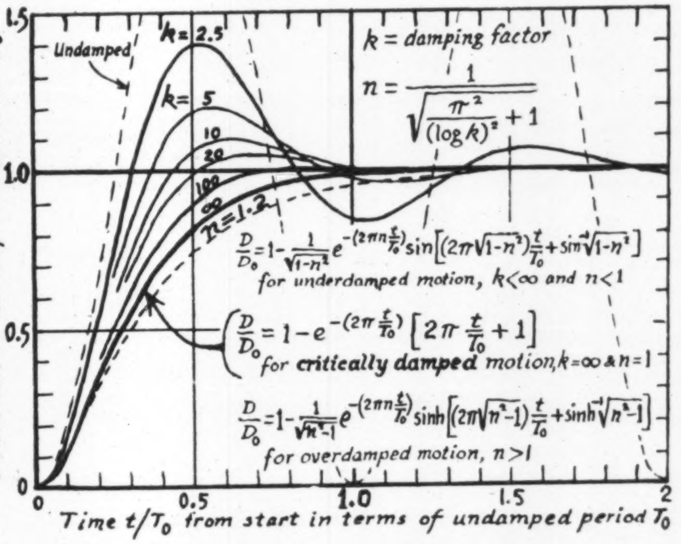


Fig. 4-13. NOTE: Damping factor k is not in percent of critical. See text.

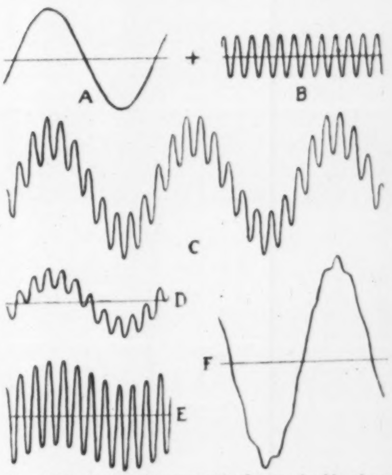


Fig. 4-14. A signal composed of two sinoids, A and B, is shown "ideally" recorded at C and "perfectly" recorded at D (all amplitudes attenuated EQUALLY).

Systems which respond unequally to high and low frequencies produce badly-distorted outputs, as shown at E (where A is halved and B doubled) and at F (where A is doubled and B halved).

for different applications with different fidelity requirements. The three types of damping are known as underdamping, critical damping and overdamping.

Underdamping ranges from zero—no damping—to critical damping. Critical damping is the point of transition between underdamping and overdamping: the adjustment is such that, following a step change, the mass comes to equilibrium position in minimal time without overshoot. Its quantitative value is customarily given as unity or 100%. Overdamping ranges from unity upward, to any value found desirable.

Mechanically, the value of critical damping is twice the square root of (moving-system inertia × spring stiffness).

Fig. 4-12 visualizes the three types of damping. Curve No. 1 represents the displacement of a moving mass subjected to a constant acceleration without restraint other than its own inertia. (This curve is a parabola—like that of a falling body.) Curve No. 2 is that of an undamped MS system subjected to one sudden or "step" input; curve No. 3, same system with critical damping; No. 4, with overdamping; and No. 5, with about 60% of critical damping (see below).

The DAMPING RATIO, COEFFICIENT or INDEX is a fraction or percent with critical damping as unity.

The DAMPING FACTOR is a non-dimensional numerical expression for the dying-down of oscillations. It is the ratio of two successive swings in opposite directions; or the reciprocal of the percent of the first overshoot after a step input. The Logarithmic Decrement is the natural logarithm of the damping factor. Among the few articles on this subject written for users rather than for designers, are those of W. N. Goodwin, Jr., who worked out in 1906 a simplified solution of the classical Gauss-Weber equations. Fig. 4-13, based on Goodwin's writings, plainly shows that overdamping (even critical damping) slows down the response too much. An overshoot of about five percent (damping index = 0.7 or damping factor = 20) seems best for most indicating instruments with periods of half a second to one second, because it makes the user feel that the instrument mechanism is "just right." Fig. 4-13 includes Goodwin's equations for the benefit of mathematical readers.

(c) MSD Systems Obeying Periodic or Random Commands.

An ideal-fidelity recorder or amplifier—in fact, any ideal-fidelity system—is one that delivers an output which is an exact copy of ANY command. Ideal systems do not exist.

Resonance.—Since every MSD system has its natural frequency, a periodic command whose frequency is exactly the same will not only sustain but BUILD UP oscillations. It will do so with the LEAST power input: it will produce the HIGHEST output/input ratio. Furthermore, "harmonics"—those frequencies which are whole-number multiples of the natural—will produce higher output/input ratios than will the intervening frequencies.

Thus, resonance makes for SELECTIVITY. This is desirable in systems such as radio receivers, vibrating-reed frequency meters, etc. Its opposite, FLAT RESPONSE, is desired in systems that must obey random commands, or commands containing different frequencies. Study Fig. 4-14.

The *square-wave command* is a good fidelity test. In Fig. 4-15 it is shown at A. An "excellent" performance (say, of a low-inertia mechanical recorder) is shown at B. The other two outputs, C and D, are those of obviously unsuitable systems. Note that D might be the record of an excellent seismometer incorrectly subjected to a test meant for a vibration recorder.

Fortunately, square-wave commands are the exception in practice: most periodic commands have no "corners."

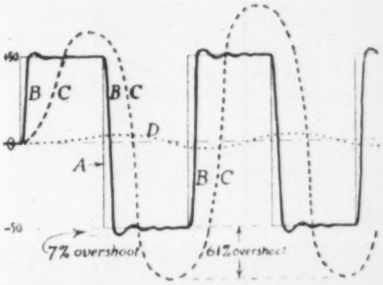


Fig. 4-15

This is why the sinoid command or harmonic-motion command (the easiest to obey) is widely used in testing for fidelity.

5. FREQUENCY RESPONSE

The frequency spectrum test of a system consists in a series of constant-amplitude sinoid commands of increasing frequency, starting at near-zero frequency (where fidelity is nearly perfect) and ending at a frequency where the system's response is weak and lagging.

Frequency-response tests are made on systems with *either* or *both* the exponential and MSD responses. The resulting amplitude ratio curves (example, Fig. 4-16) and phase-angle curves often show at a glance the usable frequency range of the device.

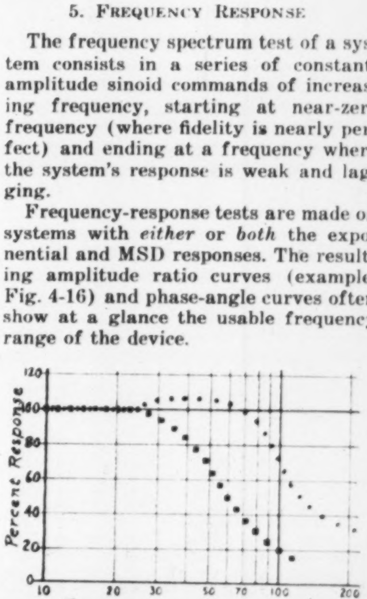
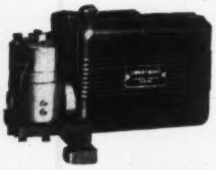


Fig. 4-16. Frequency response of two pen drives for a direct-writing magnetic oscillograph.

AUTRONIC TEMPERATURE TRANSMITTERS— Two types available: (1) T2C thermocouple converter for use with thermocouples. Bulletin A-712. (2) T2E resistance thermometer with T2A thermometer adapter including interchangeable range card. Bulletin A-706.



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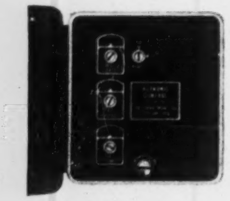

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AUTRONIC ADAPTER UNITS — Swartwout makes several adapter units to utilize any a-c or d-c signal, such as strain gauges, pH, oxygen, etc., for use with the controller, recorder, or other Autronic components.

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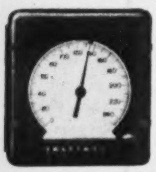
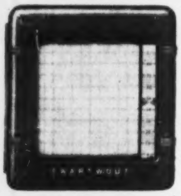


AUTRONIC INDICATOR — Rapid, accurate, miniature plug-in type instrument interchangeable with recorder. Supplied with or without set-point adjustment.



AUTRONIC RECORDER — Miniature plug-in type null-balance instrument gives true linear trace on 31-day strip chart. With or without set-point adjustment. Bulletin A-704.

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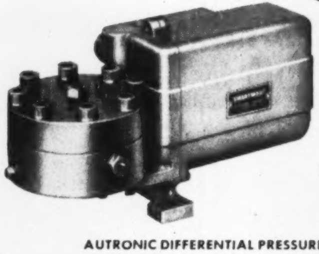

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CHAPTER XIII

AUTOMATIC PROCESS CONTROL

(With Temperature as Example)

By PHILIP ROBERT EWALD

TO discuss automatic control, no better subject than temperature could be chosen. Its control involves a study of variables and lags, as well as controller action, which includes nearly all concepts encountered in automatic process control. The word "control" calls to mind a concept of a response in some degree to a command or an order, a following or slave action, where the command may consist, for example, of an operator's varying a rheostat to control the brilliance of a lamp, or the speed of an auto with a gas pedal, or the purely mechanical control of a key-making machine with a template. The term "automatic control" brings another: the continual striving of a mechanism to maintain a variable at a set-point value, such as the maintenance of a room at constant temperature, or of a ship on a fixed course. This automatic control resembles the plain control first mentioned if the set point is varied at the will of the operator, but (as we will find) with less effort and in a more faithful manner depending on the mechanism used. It possesses this characteristic because it employes a feedback or closed-loop system, which continually compares the output with the desired set point and automatically makes a correction for any difference.

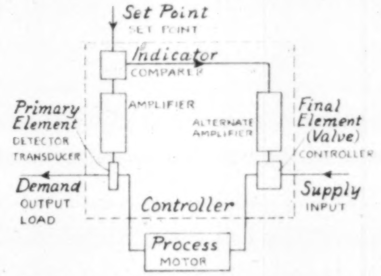

Fig. 1. Control or servo loop (Control terms are in italics; servo terms are in small caps)

Many automatically-controlled instruments of the mechanical or electromechanical type such as are applied to aircraft or gunfire control, or computing machines and the like, are termed "servomechanisms," an old word which has become popular in the literature on the subject stimulated by World War II.

We are, of course, interested in the broader concepts of process control where not only a following action but also a change of process with characteristics of its own is involved. It is customary to lump the automatically-controlled process system into two parts, the instrument and the process. Fig. 1 is an illustration or schematic of such a system with the addition of representation as usually applied to servo systems for comparison purposes.

For a couple of examples, the Fig. 1 system might be used to control flow or temperature with the symbols representing actual equipment as listed.

Designation	**Flow**	**Temperature**
Supply, Input	Water tank or main	Steam line
Final element, Valve, Controller	Air or electrically-operated valve	Air or electrically-operated valve
Process, Motor	Water pipe	Heat-transfer tank
Primary element, Detector	Orifice-manometer	Thermocouple
Demand, Output	Controlled water flow	Controlled heated water
Amplifier	Pilot-valve pneumatic relay, electric relay	Galvanometer-relay or electronic amplifier
Comparer	Spring-opposed bellows	Potentiometer

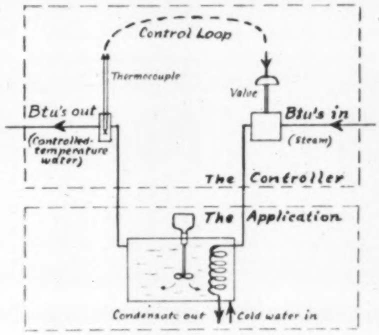

Fig. 2. Single-Capacity process

LAGS

A study of the loop shows that changes in the variable will be measured by the measuring element, a deviation from the set point noted, and through appropriate amplification, a change will be made by the final element to ultimately restore the variable to its former value. Following the loop all around, it is seen that the nature of the process will play an important part in the behavior of the loop depending on the type and amount of that ever-present problem—lag. It is the presence of this lag which differentiates most controlled processes from a mechanoelectrical servo loop. Let the process of Fig. 2 serve as an example.

There are two types of lag, dead-time or velocity-distance lag, and capacity lag. The latter can be further classified into single, double, or multiple-capacity lag. Velocity-distance lag, in our example, is the time elapsed from a sudden change in valve position to the instant the change is first detected by the thermocouple as shown in Fig. 3. It is the total time required for the changed steam flow to reach the steam coil, plus the time for thermal agitation to traverse the coil walls, plus the time for the first heated water to cross the tank, plus the time for the heated water in the outlet to reach the thermocouple. The temperature change detected by the thermocouple after the velocity-distance lag timeΔt will not be a sudden rise as was the change of steam flow, but will gradually approach a new value. This effect is due to the thermal capacity of the process, and for a simple process of the type illustrated, considering only the major capacity of the tank, is called single-capacity lag. Double or multiple-capacity lags are usually called transfer lags because of the type of lag introduced by the resistance or constriction which separates the capacities.

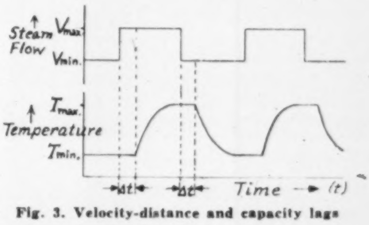

Fig. 3. Velocity-distance and capacity lags

Note that the velocity-distance lag is represented by a simple delay Δt, and that the capacity lag results in an exponential approach to the new value which may be expressed by such a relation as

$$T = \Delta T_{\max}(1 - e^{-t/L}) + T_{\min}$$

where L is the characteristic time of the process. This process has a direct electrical analogy (if the velocity-distance lag may be neglected) in the circuit of Fig. 4. Such an analog, along with the older liquid-level type, is frequently referred to in the literature for solving control problems and is employed in commercially-available process and control simulators or analogs. Here the input current I represents the Btu. input per unit time being fed into the process by the steam, R_1 the resistance to steam flow, R_2 the heat leakage from the process, C the thermal capacity of the process, R_3 the resistance to water flow, E the temperature of the water, and R_4 the load or water flow. To represent the velocity-distance lag Δt in the analog would require a complicated memory system. Fortunately, both from the standpoint of actual process control and the setting up of analogs, velocity-distance lag is, or can be made, small enough with respect to capacity lag to be neglected. This means making every effort to put the sensitive element and valve as close to the process as possible and using heat-transfer conductors with a minimum resistance, plus a thorough

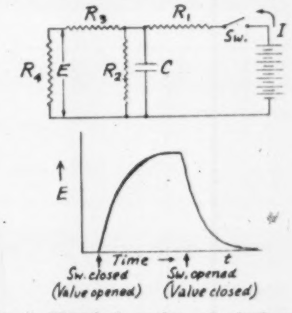

Fig. 4. Electrical analog of single-capacity process

stirring of liquids. The penalty for too much velocity-distance lag is a possible uncontrollable oscillation with the instrument on hand.

As will be seen, a large demand capacity simplifies the job of automatic control, in fact for such processes as liquid-level tanks it introduces self regulation. Note however, that the capacity must be on the demand side, a large supply capacity does not help if it follows the valve.

An example of an installation that violates these principles of good control is shown in Fig. 5.

If the process is arranged as shown in Fig. 6, along with its analog, it is known as a multiple-capacity process. Such a process is harder to control than the single-capacity type because the effect of transfer lag has become greater so that instant corrections cannot be made for disturbances. Furthermore, the change in shape of the disturbance as it passes along the process becomes greater so that correction at the valve is made difficult.

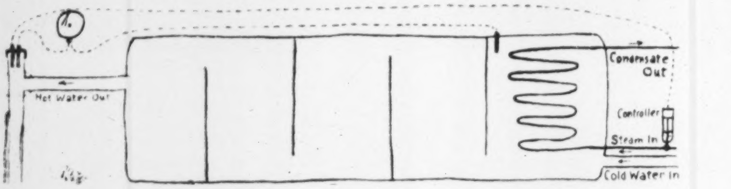

Fig. 5. "An installation where even the best temperature controller could not give satisfactory results . . . When the demand is nil, the Hot-Water-Out temperature will drop down to room temperature while steam will be generated in the right-hand end of the heater."
From "Automatic Temperature Control," by M. F. Behar, *Instruments*, Vol. 3, July 1930, pages 425-462.

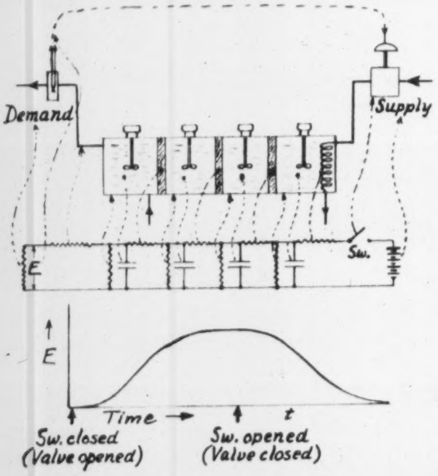

Fig. 6. Multi-capacity system and analog

UNIQUENESS OF SINOID

One type of disturbance, however, will pass through such a process without a change of form—the sine or cosine wave. This familiar plot of simple-harmonic motion will be attenuated and experience a phase shift or lag as it goes through the process, but the form will be unaltered. For this reason, it is often desirable to judge control systems by their sinoidal response, which may be done by applying disturbances of varying frequencies to the supply or demand, or to the set point, with or without the control loop broken. Amplitude or phase changes may then be easily determined, and form a basis for rating a system. The story is not all told however, unless the square-wave response is also noted as in Fig. 3, and, if means are provided for measuring the change of wave-form as well as amplitude and phase, a good idea of the performance of the system is available.

CONTROL THEORY

We have seen from the above that a disturbance is altered in form or phase as it passes through the process. If it is now fed back to the beginning of the process in the new form, the next trip through will yield a further change, and so on ad infinitum. Obviously, this feeding back must be done in such a manner that disturbances are quelled rather than enhanced. *The purpose of automatic control is to feed the disturbance back to the valve in such a manner and with such amplitude that the deviation of the measured variable from the set point is held to a minimum.* This may mean a minimum peak value, or a minimum average or a minimum r.m.s. deviation depending on the needs of the process under control. How this is done depends also on the available instruments. Instrument manufacturers have built up a vast store of experience in the control of processes, and examples are available of the control to be expected from various settings of different modes of control—or different types of control action—in a wide variety of processes. Although the final "tuning" or setting of these modes is nearly always done by trial and error with the instrument installed in the system, some generalities may be followed either from experience or a general knowledge of control behavior so that suitable modes may be selected beforehand for a given control job. The fundamental modes used in process control are described in the following paragraphs in a somewhat idealized manner to illustrate the points which might be lost in the actual graphs of installed instruments.

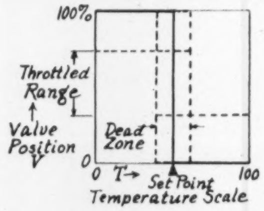

Fig. 7. On-off mode of control

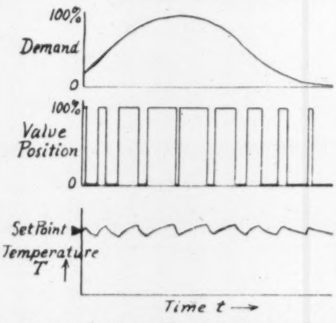

Fig. 8. Action of on-off mode of control

ON-OFF OR TWO-POSITION

On-off control, as the name implies, turns all the steam off when the temperature rises above the set point by a fixed amount, and on when it falls below. This action may be represented by Fig. 7. The less sensitive the instrument, the wider the dead zone in which the temperature may wander without affecting the valve setting. This type of control is useful in the presence of large capacities where the all-or-nothing supply will not introduce large fluctuations immediately. For this reason it is suitable in many temperature-control problems. The action is illustrated in Fig. 8.

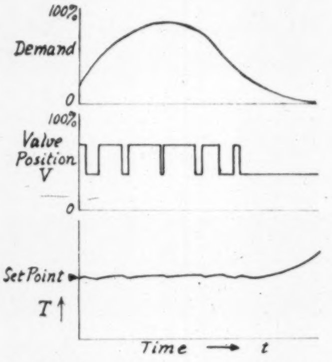

Fig. 9. Effect of throttling on-off control

Optimum adjustment usually means setting the supply-demand ratio to the point where the valve will be open half the time. This will minimize oscillation due to lag. Height of the deviations due to valve action may be reduced by throttling the valve to a fraction of full travel for each stroke. This yields smaller deviations unless the supply-demand ratio changes beyond the control limits set by the valve, in which case the drift from the set point known as "droop" or "offset" occurs as illustrated in Fig. 9. The optimum settings for this throttled control are thus limited by considerations of the possible supply-demand ratio changes.

STEP OR MULTI-POSITION

An improvement over on-off control is the step control illustrated in Fig. 10. It permits control of processes with smaller capacity because it gives a valve setting roughly proportional to temperature deviation. However, except for a few cases where it is mechanically easy to fabricate such a control, the true proportional or positioning mode of control of Fig. 11 is almost universally used.

THROTTLING OR PROPORTIONAL-POSITION

This mode of control is sometimes called throttling control in that it operates as a continuously-variable constriction. It is often supplied with the degree of control or throttling percent made adjustable to suit the process. As with the previous modes, proportional control must be set with a sufficiently narrow band to avoid droop. The continuously-variable feature permits use with low-capacity processes, limited only by the amount of velocity-distance lag present. However, with low capacity, too narrow a throttling band results in wide oscillation. With only one adjustment, this mode of control is easily tuned in to the process. As will later be seen, another possible name for this mode, based on its action, is damping control.

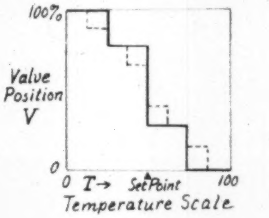

Fig. 10. Step mode of control

FLOATING

Elimination of droop is achieved by the use of floating control which gets its name from the fact that the valve position is not tied to any temperature as in proportional control, but that it keeps moving until the temperature is at the set point. This is best achieved by an action where the valve velocity is proportional to the temperature deviation from the set point as illustrated in Fig. 12.

AUTOMATIC-RESET OR PROPORTIONAL-SPEED FLOATING

Similar action is sometimes achieved by simply resetting the set point of a proportional controller, hence the name reset control. Since the valve velocity is proportional to temperature deviation, the term velocity control is sometimes used, and because the valve position is a function of the integral of temperature deviation, or depends on how long and how much of a deviation there is, the action is sometimes referred to as integral control. A little study will show that this type of control will do a good job if there is no velocity-distance lag in the process. The presence of this lag means continual oscillation, however, if only the floating made of control is used. For this reason, floating and proportional control are usually used together, the most popular combination at the present time, to give the freedom from droop supplied by the floating mode, and the necessary damping supplied by the proportional mode.

RATE OR DERIVATIVE

A further improvement in process control is achieved if some action is taken before the deviation becomes appreciable, that is, the instant it starts. This is an impossibility if "the instant it starts" refers to the *controlled* temperature; therefore the action is taken before the deviation signal of a (relatively) slow measuring system becomes appreciable. This action is achieved by making the valve position proportional to the rate of change of measured temperature as shown in Fig. 13.

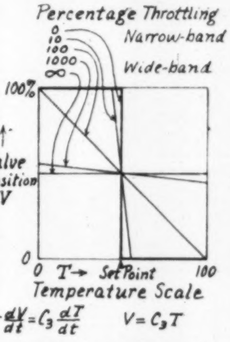

Fig. 11. Proportional mode of control (positioning, throttling, damping)

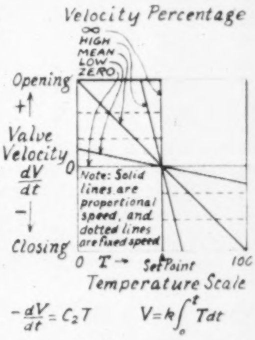

Fig. 12. Floating mode of control (reset, integral, velocity)

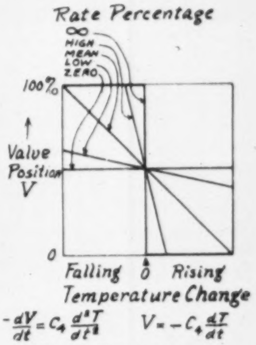

Fig. 13. Rate mode of control (derivative, acceleration)

The popular name for this mode is rate control, based on the proportionality between valve position and rate of temperature change, or derivative control since the expression dT/dt is the same as rate of temperature change. As will be later seen, from the dynamical standpoint, it might well be called accelerating control. This mode in itself cannot control a process because it does not depend on a measurement of a deviation from the set point. Consequently, losses in the process would cause a steady drift of temperature were this the only mode to be used. As a result, rate control is always used with proportional or floating control or both to serve as a booster, or, to look at it another way, to act as an inertia to change. A popular method of approximating this mode is to narrow the proportional throttling band as the temperature deviation from the set point increases, and to widen the band as the return to the set point starts.

INVERSE DERIVATIVE

If exactly the opposite procedure is followed, that is, to widen the throttling band as the temperature deviation increases, a mode known as inverse derivative will be in effect. This is a recently-introduced[1] mode of control which at first glance would appear detrimental. The answer of course is in the application to which it is put. Conventional derivative control works on the assumption that a deviation once started will continue in that direction for some distance; the steeper the deviation curve, the farther the ultimate deviation. This is true in large-capacity processes for instance. However, there are many processes, usually of low capacity, where there is considerable random or statistical deviation. It is for these cases (where a sudden abrupt deviation does *not* mean necessarily that there has been a major change in the process) that inverse-derivative or inverse-rate control allows the process to ride through the disturbance which otherwise might lead to large-amplitude oscillations.

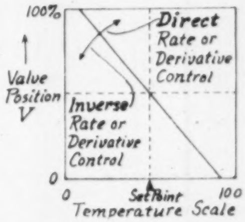

Fig. 14. Method for obtaining rate control

Since rate control, both direct and inverse, can be approximated by varying the proportional band width, it is possible to represent these modes by a rotation of the proportional characteristics as shown in Fig. 14.

There are, of course, an infinite number of possible modes of control of higher order than those discussed and of various gradations and combinations of those considered.[2] For purposes of process control, the higher-order-than-rate modes could have little application, and it has already been seen that on-off and step control are special cases of proportional mode. It hence evolves that the only combinations of control which need be considered are:

1. Proportional
2. Floating
3. Proportional plus floating
4. Proportional plus rate
5. Floating plus rate
6. Proportional plus floating plus rate

If we consider the last combination, all the significant modes are included,

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(1) C. B. Moore, *Instruments*, **Vol. 22, March** 1949, pages 216-219.

(2) See "Fundamentals of Instrumentation" by M. F. Behar, Instruments Publishing Co., Pittsburgh, 1932. Chap. III, Sections 10 and 11.

so that the dynamic equation of motion of the valve may be written by summing all the modes:

$$-dV/dt = c_1 + c_2T + c_3dT/dt + c_4d^2T/dt^2$$

BRIEF ANALYSIS

Readers acquainted with mechanical-vibration theory[3] will recognize the similarity of the above equation to that of a forced-oscillating system, and hence a mechanical analogy for a process controller is a possibility[4] as well as the electrical and hydraulic analogs mentioned. Here c_1 is an arbitrary constant for initial conditions, c_2 represents a spring or restoring-force constant, c_3 is a damping-force constant, and c_4 represents an acceleration-force or inertia constant. This equation represents the action of the instrument on the valve as a result of temperature changes at the measuring element. To express the action of the entire system, it must be remembered that the closed control loop now makes the temperature T itself a function of the valve position V, so, depending on the type of process being considered and the simplicity of the resulting equation, a substitution is made of T for V or vice-versa, and the resulting equation for the entire system then examined. If the equation can be put into suitable form, it is possible to determine whether or not the system will be stable for the possible values of the constants.[5] The prediction of the behavior of a control system by mathematical methods, while extensively worked out for servomechanisms, has been used to a lesser degree in process control work. In such a field it is difficult for the methods of mathematics to compete with judgment by experience, but the opening is there, and some day process-control people will be buying and setting their control instruments with the aid of charts and special slide rules just as is done today for a multitude of engineering problems.

To close with a continuation of the discussion of possibilities, just what would be an ideal controller? Actually, if a process were perfectly designed with plenty of spare supply and demand capacity, it would need no control instrument and would run right along wherever it was set. Such a procedure is usually quite expensive, so the part of the instrument ultimately resolves itself into that of a necessity as a cost saver. The ideal controlling instrument might have the features shown in Fig. 15. It would have a high-speed chart drive for studying transients and control characteristics while making adjustments to the process and also a low-speed drive for economy during operation. There would be three control-mode adjustments, proportional, floating, and rate. The latter would cover both positive and negative ranges to give either direct or inverse-derivative action. Of course the conventional set-point and valve-position indicators would have a prominent place. With such a control instrument, the operator would be ready to tune in his process, no matter how cantankerous, and obtain a really satisfactory job of automatic control.

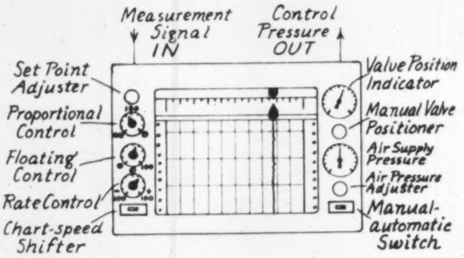

Fig. 15. An ideal control instrument

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(3) A good example among many books is Den Hartog's "Mechanical Vibrations."

(4) P. R. Ewald, "Forced-oscillation Approach to the Problem of the Automatically-controlled Continuous Process," *Instruments*, Vol. 16, August 1943, pages 474-476, 506.

(5) Following the early writings of Routh, and the later ones of Nyquist and subsequent workers, there have been established criteria which can be used with the equations of a system to determine whether or not it will oscillate and what the degree of damping is.

APPENDIX

To supplement the above discussion, examples of actual tests run on controllers in operation are taken from articles in *Instruments* (July and October 1943 by J. G. Ziegler; and March 1949 by C. B. Moore) condensed here to illustrate the proportional, reset, and rate modes of control.

In Fig. 1A, a system using the proportional mode was given a momentary change in supply for several control settings. Note that the proportional mode units are in lbs. per sq. in. per in. of deflection of indicator from the set point rather than the usually expressed percent of full scale deviation needed for full range of valve travel.

Here it is seen that too narrow a band yields oscillation, while too wide a band results in wide deviations with slow recovery. The optimum, at setting 10, shows the minimum total deviation from the set point.

Fig. 2A shows the result of applying step changes in the load at several settings. Too narrow a band yields oscillation as before, but for this case, even at the optimum setting, the problem of droop is encountered, calling for a resetting of the control set point.

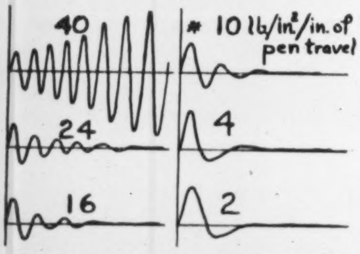

Fig. 1A. Proportional mode with momentary changes in supply.

In Fig. 3A, reset is added to the proportional mode in increasing amounts until oscillation occurs. The optimum value which produces a minimum deviation is at 0.8 per min. These units are the number of times per minute that the given reset rate could reproduce the change in valve position caused by the proportional mode for a given deviation from the set point. The reciprocal of this unit is used in Figs. 4A and 5A.

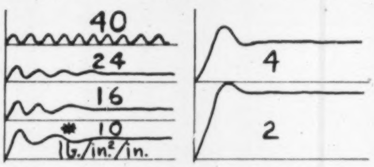

Fig. 2A. Proportional mode with step changes in load.

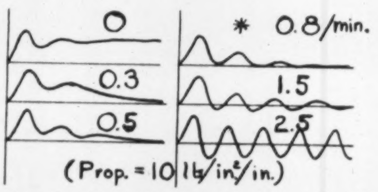

Fig. 3A. Proportional mode plus reset with step changes in load.

Further improvement in control action is attained in the example of Fig. 4A where up and down step-load changes are applied to a system, first with only optimum proportional and reset modes, and then with the optimum rate mode added. The differences noted in responses to up and down load changes are attributed to changing valve characteristics.

Note that all the above examples were run on processes with relatively large capacity. Where capacity is small, the inverse rate or derivative mode comes into its own as shown in Fig. 5A where the action of a liquid-flow controller with two, then three, modes is illustrated. The units of rate control are the number of minutes by which the rate mode advances the time it would take the proportional mode to move the valve a given distance for a given rate of deviation change.

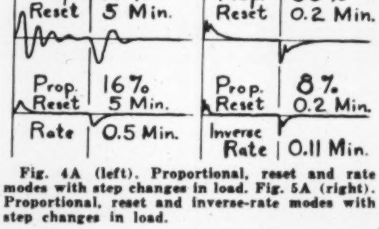

Fig. 4A (left). Proportional, reset and rate modes with step changes in load. Fig. 5A (right). Proportional, reset and inverse-rate modes with step changes in load.

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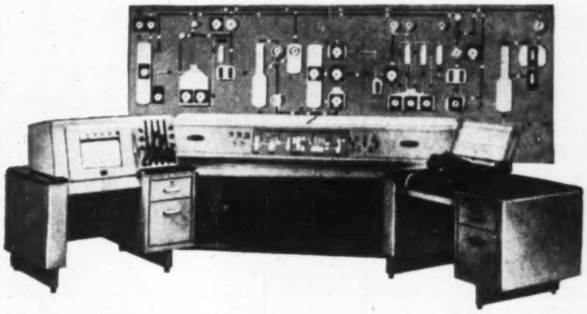

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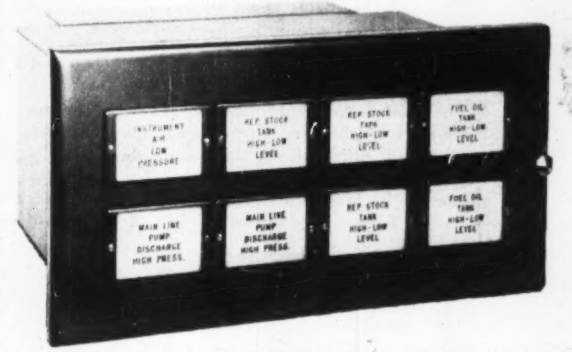

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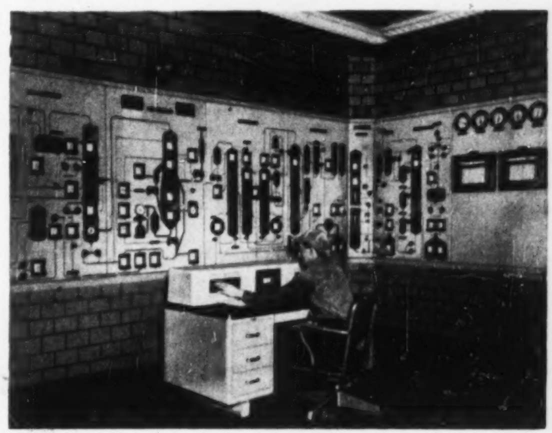

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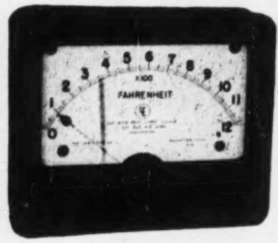

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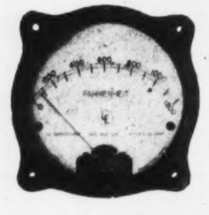

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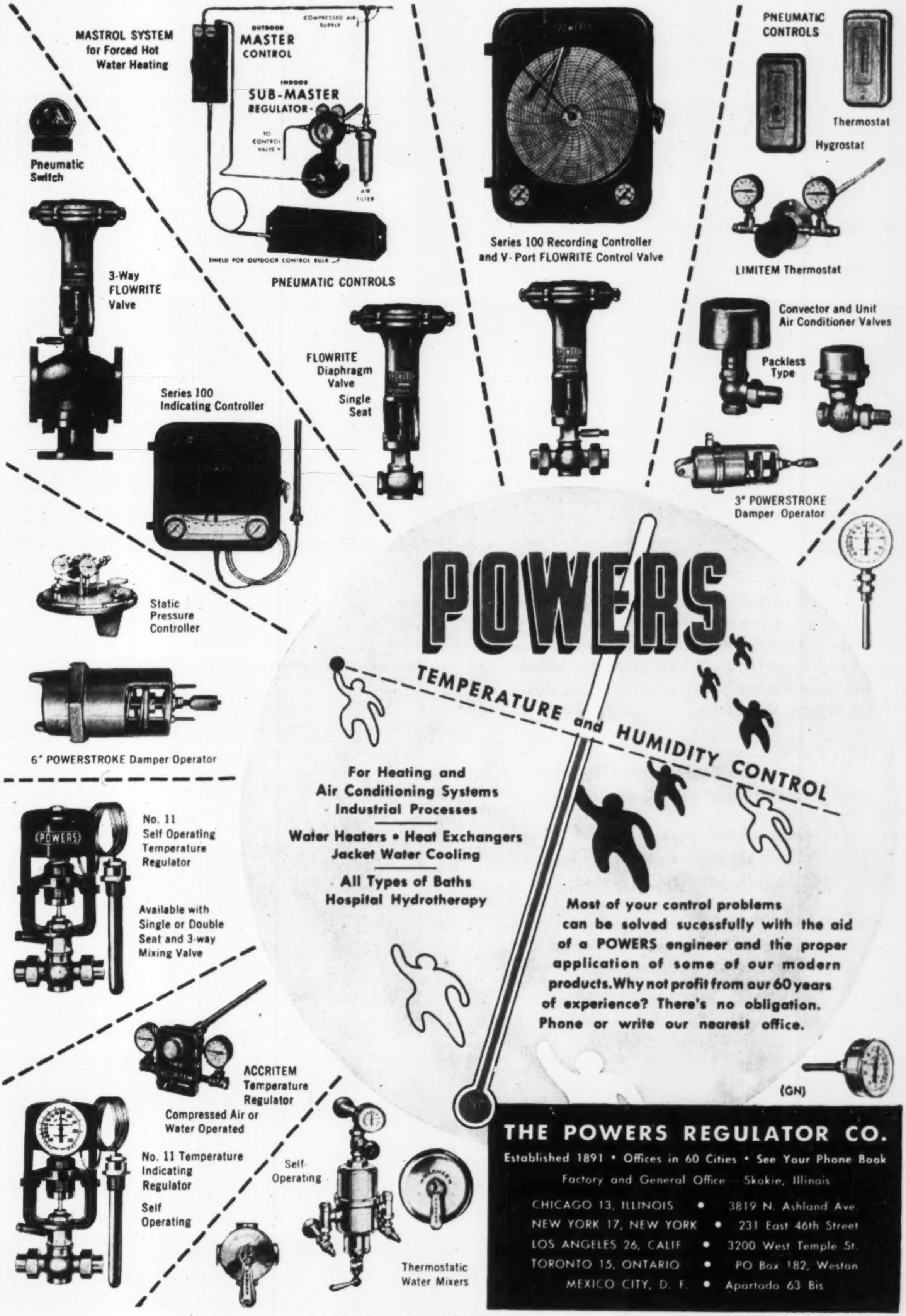
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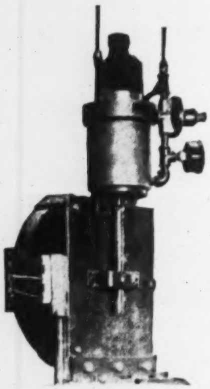

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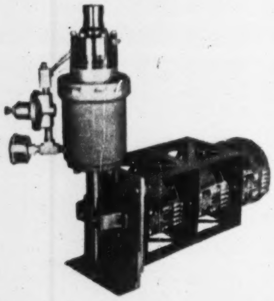

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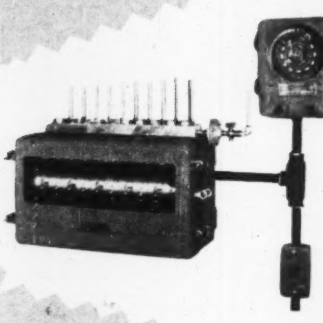

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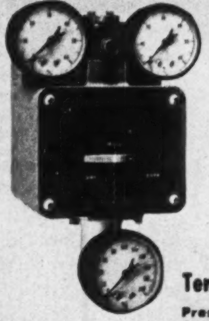

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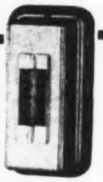
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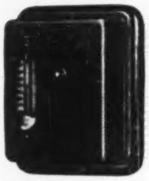
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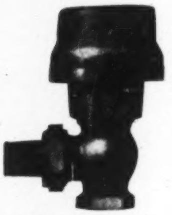
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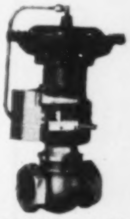
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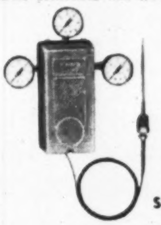
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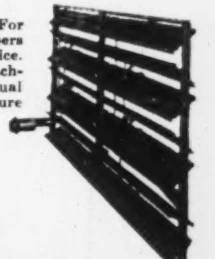
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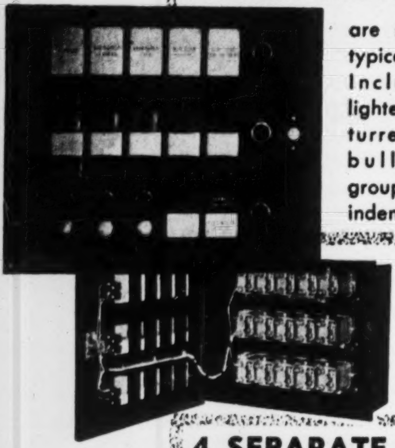

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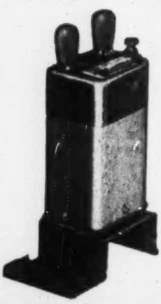

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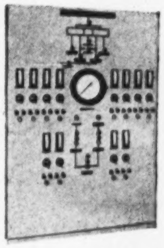

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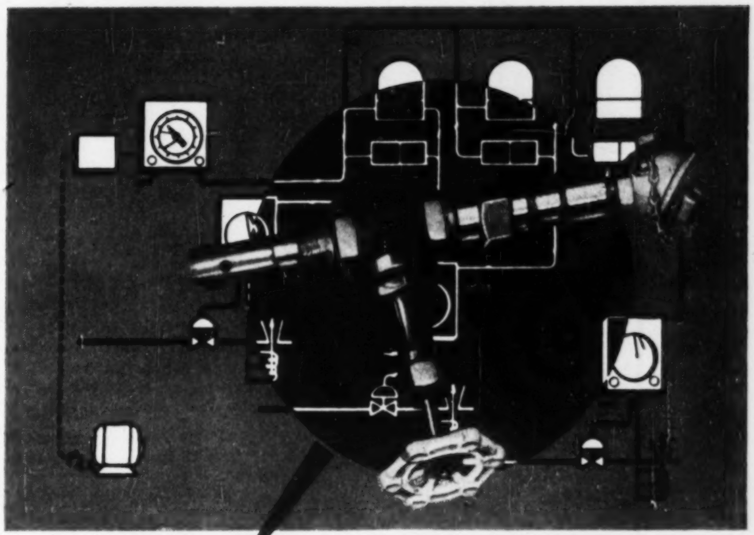

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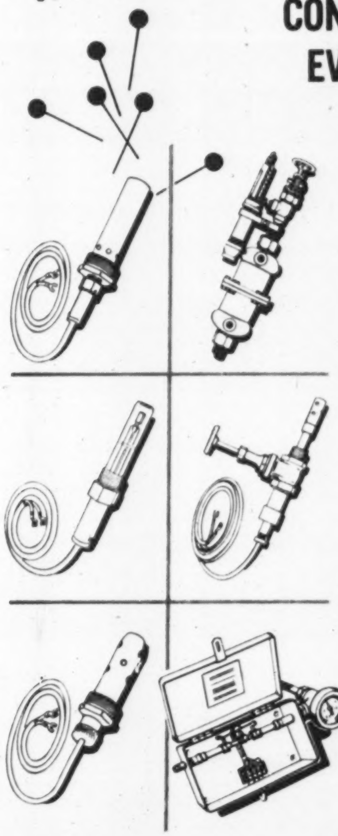

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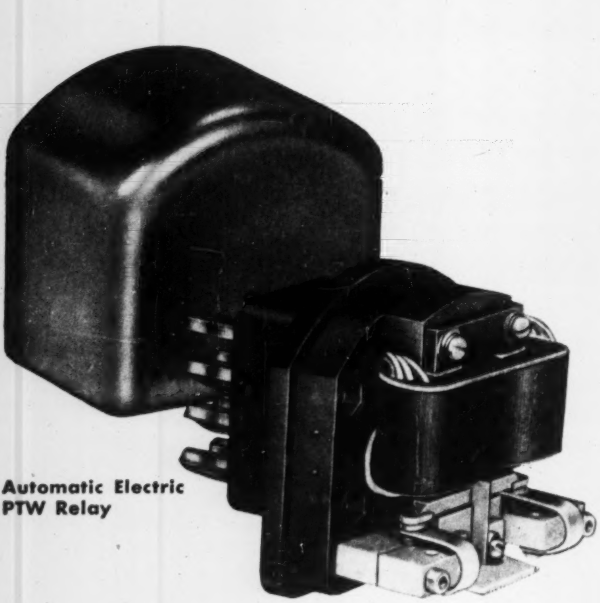

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Mounting—Jack mountings, available for flush or surface mounting.

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CHAPTER XIV

SERVOMECHANISMS—AN INTRODUCTORY TREATMENT

By M. F. BEHAR

PART 1—FOR ALL READERS OF THIS BOOK

especially the non-mathematical readers who have skipped Chapter XII on the Dynamic Characteristics of *Measuring* (not automatic-control) *Systems;* but who nevertheless want to know what a Servomechanism IS and who should know what a Servomechanism is not.

FIRST, a servomechanism is a servant. It obeys a command. In the beginning of the art (now a science and an industry) the command was always issued by a human being. Today, manual commands are outnumbered by commands from measuring systems. Thus a servomechanism is a member of the class of devices which obey manual or measuring-system commands—but it is the only such servant that has a "brain" of its own.

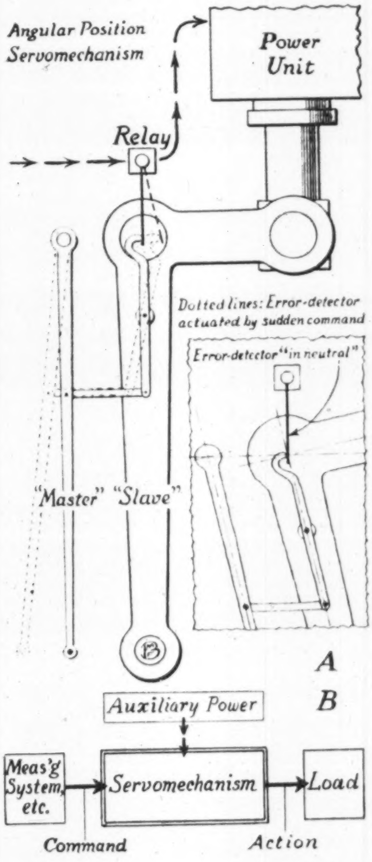

Angular Position Servomechanism
Power Unit
Relay
Dotted lines: Error-detector actuated by sudden command
Error-detector "in neutral"
"Master"
"Slave"
A
B
Auxiliary Power
Meas'g System, etc.
Servomechanism
Load
Command
Action

Fig. 7-1. Simplified presentation of one type of servomechanism; and simplified block diagram which is true of all types of servomechanisms.

(A) In this sketch the "master" resembles a recorder pen-arm but it might be the deflecting member of any measuring system; or it might be a manual-command knob or lever. The "relay" might be a large hydraulic pilot valve imposing a drag on the commanding element, but it usually would be a dragless relay.

(B) The "master," the power source, and the load, are not components of a servomechanism. The combination of a power source and servomechanism would be a machine such as a bulldozer. The combination of a power source and a servomechanism and its load would be a truck, an airplane, etc. The combination of a measuring system and a servomechanism is an automatic controller or regulator. But the combination of a MANUAL "command station" (such as a lever or knob) and a servomechanism is a servomechanism.

Second, a servomechanism is a mechanism. The auxiliary power (arrows in Fig. 7-1A) may be compressed air, or d.c., or a water-wheel, or a clock spring wound periodically, or a.c., or steam, or hydraulic fluid, or "atomic" power, or a rotating shaft—but the servomechanism is a mechanical servant. As a rule, it utilizes power for moving heavy loads in obedience to weak commands. The original power *source* is immaterial but the result is a *mechanical* displacement (translational or rotational).

Mechanical displacement being change of position, the command is of the form, "Move this heavy thing from *here* to *there*," which a servomechanism understands. A servomotor would not know where to stop; a servomechanism makes its servomotor stop at the right place.

At the right place implies at the right time: a servomechanism knows *when* to stop. Therefore it knows where and when *not* to stop. *It knows its own error at all times.* An essential element of every servomechanism is often called the "error detector." But a servomechanism can *measure* its own error; it can measure its *instantaneous* error. And a highly-developed modern servomechanism can measure the *rate-of-change* (and other time functions) of its own error.*

Thus a servomechanism can obey a RANDOM command—which means that when the master says "Follow me with this heavy load" it will do so to the best of its power and of its ability. "To best of its power" means the horsepower or kva. rating of its servomotor, minus inertia, friction, etc. "To the best of its ability" means that *it tries at all times to minimize its own error*: to reduce its error to zero if it is designed without any dead zone or differential gap; to a harmlessly small value if, for example, it is designed with an adjustable electrical-contact device. Moreover, it always succeeds in zeroing its error (or minimizing it) if it is in good condition. It seldom suffers from steady-state load error or droop.

Finally, an attribute of highly-developed servomechanisms is that they zero their error in the least possible time and with little or no hunting. This attribute is known as *stability.***

In these four expressions—"a random command," "follow-up," "zeroing the error" and "stability"—lies the sharpest distinction between a servomechanism and any other kind of mechanical servant that moves a heavy load in obedience to a weak command. A servomotor is only a motor; but a servomechanism—well, imagine a pilotless jet-copter able to fly or to hover, to zoom or to dive; and imagine yourself sitting in front of a map table, moving a stylus-contact slowly over the map to command the jet-'copter where to go and twirling an altitude-command knob from time to time to make the jet-'copter take off and hurdle mountains and make landings and take off again. This whole system—the combination of control desk and guided aircraft—is a servomechanism.†

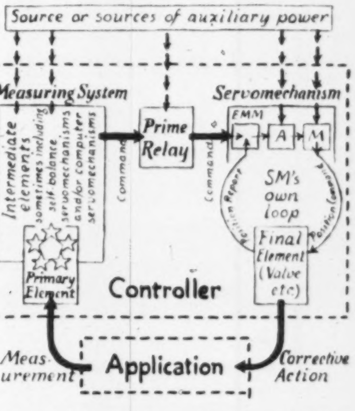


Fig. 7-2. Automatic control system whose controller includes a servomechanism instead of a mere servomotor. The command to the servomechanism is not shown as a change of position (as in "A" of Fig. 7-1). Reason: in practice many commands are changes of voltage or pressure. Even mechanical commands are seldom straight-line or small-angle but are rotations over angles greater than 360 degrees.

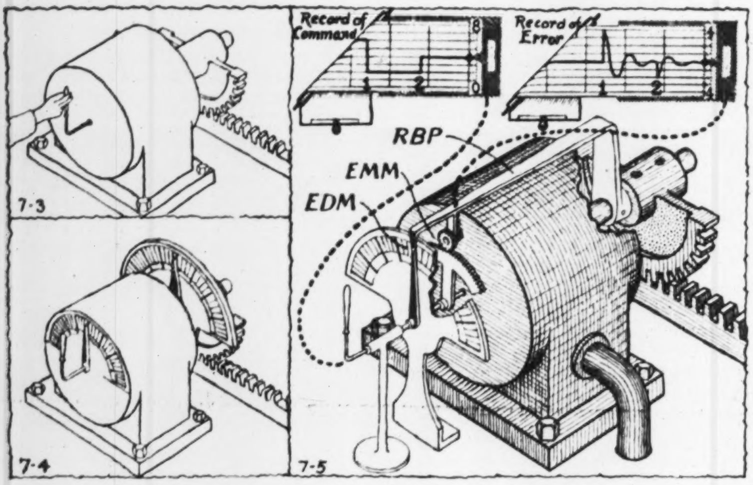
Actual servomechanisms, of course, are far from spectacular; most of them are used as already mentioned in other chapters: as valve positioners and in other seemingly inferior but really essential roles—not only in controllers, but in computers, in telemeters, in recorders, etc. Often, the servomechanism is the most important component; sometimes the costliest; but it always is a mechanical servant which obeys the measuring system's position command. This obedience to the commands of the measuring system is brought out in Fig. 7-2.

---

*Implying that the relay in Fig. 7-1 must be a power modulator, not a mere power switch (all-or-nothing). This view is maintained throughout most of this Chapter in order to avoid complicating the presentation. However, there are modern servomechanisms whose relays are of the simple on-and-off type. Their performance is excellent in the particular applications for which they were designed. Therefore, the relay in Fig. 7-1 *may* be a mere switch. This is the reason why the linkage which actuates the relay is labeled "Error Detector" and not "Error Measuring Means."

**Same word as a measuring property of a measuring instrument, but diferent meaning: *dynamic* stability.

†Technically it is more, in two ways: (1) it is a plurality or multiplicity of servomechanisms; (2) it incorporates the aircraft power plants which are not essential components of a servomechanism. But the reader will overlook this technicality.



Figs. 7-3, 7-4 and 7-5

Note that the master (the measuring system or manual knob) may command the servomechanism directly as in Fig. 7-1 or through one or more stages of power amplification as in Fig. 7-2.

Important Distinctions

In the foregoing paragraphs, where the two words beginning with "servo" were printed, the reader's eyes have had to pause and go back several times, to make sure what was meant, although both words were used correctly. Since the mid-thirties these words have been used indifferently in some books and in many articles. Even the shorter noun "servo" has been used to designate *either* a servomotor or a servomechanism, without hinting which is meant. At this point, therefore, it may be well to repeat some distinctions stated briefly in Chapter I; and to re-state them in their 1927-1930 elaborateness:

A self-operating measuring instrument or automatic controller does not actuate or operate its final element by means of a servomotor.

A relay-type (or servo-operated or auxiliary-powered) instrument—for measurement or for automatic control—embodies a power unit which operates the final element. This power unit is a servomotor but the term power unit was proposed when formulating Instrumentation, to distinguish this element from a full-fledged servomechanism.

Some relay-type instruments embody full-fledged servomechanisms whereby the final element is positioned with speed and precision.

Note carefully:

A servomechanism ordinarily embodies a servomotor, which is called "power output element" or "servomotor" or simply "motor" in the current literature on servomechanism theory. Functionally this element is the power unit.* Therefore, in the remainder of this chapter it will be called the power unit generically (or by specific names such as "reversing motor," etc.). In Fig. 7-2 it is labeled *M*.

Now for the distinction between servomechanisms and automatic controllers, governors, regulators, etc. A direct quote:

"Servomechanisms are the precious fruit of so much intense work by so many geniuses, that it's a crying shame to have the meaning of the purely technical term servomechanism expanded wantonly and cheaply. . . . The thermostat in your wife's electric iron, the water-level float valve in your bathroom, the voltage regulator in your car, the AVC in your radio, and hundreds of other automatic gadgets, are error-correcting devices but they are not servomechanisms. (Common misapplication of the dictum *de omni et nullo*: 'cats are animals, dogs are animals, therefore dogs are cats.') . . . A servomechanism may serve a primary element or a measuring system, such as a manometer, a thermocouple, a tachometer, etc., but it does not include or comprise this element or system whose commands it obeys. Slave and master must not be confused—even when the slave is Socrates and the master an otherwise undistinguished person. . . . The *combination* . . . is . . . an automatic controller."

This was published before the first book on servomechanisms came out. Now, some writers on servomechanism theory assert that all automatic control systems are servomechanisms. They have a perfect right to do so; instrumenticians have an equal right to declare: "We hold the truth pictured in Fig. 7-2 to be self-evident: that with the exception of certain automatic position-control systems, not a single automatic-control system in all the world is a servomechanism."

The automatic position-control systems which are controllers and servomechanisms at the same time are the contour controllers on machine tools, and other mechanisms in which the command is a continuous or frequent change of position. (Even so, extremists among Instrumenticians assert that the simplest template is a "master," hence not part of the servomechanism.)

Qualitative Description of Performance

(From here on, "servomechanism" is abbreviated "SM.")

Consider first the mechanism sketched in Fig. 7-3. It is a positioning mechanism but not necessarily an SM. The "finger-tip command" feature might represent an ordinary switch or another form of on-and-off power relay: pneumatic, hydraulic, electrical, etc.—in which case Fig 7-3 would be a motor, not an SM. The picture doesn't show the load which, as the size of the rack-and-sector suggests, is a heavy one. Let's assume that the load is the steering machinery of an ocean liner or of an aircraft carrier. The lever now ceases to be a switch and becomes, functionally, the "master" of Fig. 7-1. If you are steering the ship, you will not be operating an off-and-on relay: when you wish to change the rudder position you will change the position of the input lever, knowing that the power unit will immediately start rotating the output shaft, and expecting that this displacement will stop when the output shaft's position corresponds exactly to the position of the input command. The Fig. 7-3 device now becomes the Fig. 7-4 SM which is provided with input and output dials. These dials, though not essential components of any SM, are added to enable you to observe the performance of this SM. You decide to observe its performance by observing what it does (1) when you shift the input lever suddenly, (2) when you move it at constant speed, and (3) when you jiggle it back and forth.

(1) When you shift the input suddenly, you observe that the output shaft does not instantly move with its heavy load to its new position.

This is natural. To make even a light object move from rest to a high speed in a short time, and then to stop it in its new position, takes lots of power. If the "light object" weighs only 150 grains, the requisite power to give it the "high" speed of 2770 feet per second in the "short time" of 0.0015 second will be about 200 horsepower. (This light object, as ex-riflemen have guessed, is the M2 bullet.)

(2) When you move the input lever s-l-o-w-l-y, the output shaft follows the command so faithfully that you cannot see the SM's error—the angle between the input and output pointers.

(3) When you jiggle the input lever rapidly, the output shaft stands still. The error is fully 100 percent.

These qualitative tests have brought out almost all that has to be known in a general way about the three principal performance characteristics of a heavy-duty SM.

A fourth characteristic appears—also qualitatively—when the ship is in drydock: with only air resistance on the rudder, you discover that the response to a sudden-shift command is faster than with the rudder in water (as expected) and that there is some overshooting. Evidently, water had a stabilizing influence. Evidently, also, the SM had been so designed or adjusted that the water served as *critical damping* (see Chapter XII).

---

*In some servomechanisms the power source is a rotating shaft and the power unit is not a true motor but a clutch-like device: a mechanical power modulator. Therefore it cannot be stated flatly that *every* servomechanism embodies a servomotor.

A fifth characteristic was obvious during all these tests: there was no "feel-back" as there is, for example, in aircraft torque amplifiers. (A good SM imposes no drag on the measuring instrument or relay which commands it, and its over-all power gain is infinite.)

Simulating Actual Tests. As in performance tests of actual SMs, your hypothetical SM may be instrumentized. The equipment is shown in Fig. 7-5. Note the repeat-back pointer *RBP*. It, or its equivalent, is an absolute essential of an SM, for every SM must know its own error. Note also that the special shape of *RBP* resembles the usual shape of the feedback loop in the usual SM diagram although *RBP* is definitely not a feedback.

Mistakes are sometimes made by experts who use the same graphic symbol for the repeat-back and the feedback and then confuse them although they know that feedback is the feeding of a part of the output ENERGY (OR POWER) into the input, whereas repeat-back is an OPEN-ENDED indication.

In Fig. 7-5, the input lever actuates the recording instrument at the left. This is a low-inertia instrument like an oscillograph. Its scale reads 0 to 8, with 4 representing the SM's mid-position. Its chart travels leftward, so that the record of input commands is like the usual time graph.

For the error, you have both an indicator and a recorder. The tips of the input pointer and of the *RPB*, together with one graduated scale for the pair, provide you with so convenient an error-detecting means (*EDM*) that you can use it as an error-measuring means when things don't happen too fast for your eyesight. The true *EMM* consists of a sector-and-pinion and its operation is self-explanatory: it actuates an error-recording instrument (the one on the right) also having low inertia. The scale of this error recorder is graduated plus and minus 4, with zero center. Ideal performance would be a constant zero regardless of the randomness of the command.

Note that these two autographic instruments do not give you records of input and output, but of INPUT AND ERROR.

First test: At time 1 you have suddenly moved the input lever from 6 to 2. The error record shows an immediate error of four scale divisions, followed by an overshot of 2 below the zero axis, then 1 above, then 0.5 below, etc.

Second test (at time 2): You have suddenly moved the input lever half as much: from 2 to 4. The error record resembles that of the first test. This shows that the extent of a sudden command does not matter: the SUDDENNESS causes the error.

As mentioned earlier, this particular SM performed without hunting when the rudder was submerged. The error recorded in Fig. 7-5 was produced in a dry-dock test. Such wiggles of the error record would ordinarily betray "too much flywheel effect," i.e. excessive inertance. The major component of the total inertance often is an SM's own power unit—especially if this power unit is an electric motor. As a rule, the higher the inertia, the higher the damping required, and the slower the SM.

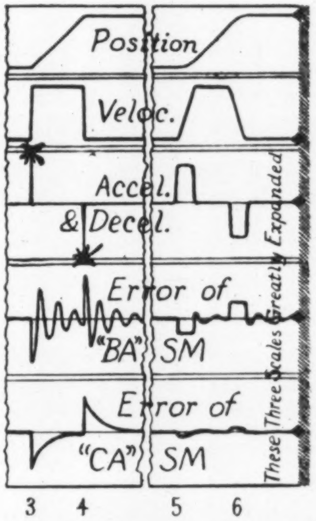


Fig. 7-6. An imaginary five-pen recorder traces records of the position commands (top) and of the performance of two servomechanisms, one "badly adjusted" and the other "correctly adjusted."

Uniform-velocity Commands: For the third and fourth tests let's imagine that you are comparing the performance of two SMs, one badly adjusted and the other correctly adjusted. Now the instrumentation consists of the ideal five-pen recorder shown in Fig. 7-6. The upper three pens write input records: first, the position of the input lever; second, the instantaneous velocity of the input lever; third, its positive or negative acceleration. The fourth pen is actuated by the error-measuring means of the badly-adjusted SM; the fifth pen by the *EMM* of the correctly-adjusted SM. Here is what the records show:

Third Test (left-hand half of Fig. 7-6): At time 3, your command velocity changed from zero to a constant value ALMOST SUDDENLY (note slight off-verticality of velocity record at time 3); and again almost suddenly back to zero at time 4. At time 3, there was a "very high" positive acceleration of your input lever and at time 4 a "very high" negative acceleration (those aren't palm trees but ink blots: acceleration-recorder pen hitting the stops). The error records show serious hunting by the badly-adjusted SM at time 3 and at time 4; and excellent performance by the correctly-adjusted SM.

Fourth Test (right-hand half of Fig. 7-6): This may be likened to gently starting and gently stopping a car. You command the output shaft to be accelerated gently at time 5, and decelerated gently at time 6 just before the desired position is reached.

It would appear at first thought that the gentle acceleration can easily be realized in practice but that only an extraordinary mechanical or electrical "brain" could know when to apply the brakes before the load arrives at its destination—especially in view of the fact that an SM receives RANDOM commands, so that there is no opportunity of installing in a fixed place the equivalent of a "slow" road sign. In practice, however, the easy stop is obtainable—not merely by damping but because the SM knows its own error at all times. Its error-measuring means and its amplifier issue commands to its power unit—as a rule *continuously*. Therefore, when the error is diminishing, the command to the power unit is VARIED in a predetermined manner to prevent overloading.

PART 2—PHYSICAL ELEMENTS OF TYPICAL SERVOMECHANISMS

Figs. 7-7 and 7-8 show the principal physical elements of two electromechanical SMs. In each, the input command is mechanical, the error-measuring *EMM* is mechanoelectrical, the external source of power is electric, the amplifier *A* which valves or modulates this power is purely electrical, and the power unit *RM* is a reversing-type electric motor, that is to say, an electromechanical translator, transmuter or transducer. (Since this is written for instrument men, the *EMM* has been emphasized in both drawings, and the other components subdued.)

The large repeat-back pointer which was the purposely-exaggerated feature of Fig. 7-5 is absent but its position-reporting function (which is an essential one as indicated in Fig. 7-2) is accomplished by having the output shafts extend rearward (leftward) coaxially with the input spindles. This is an actual arrangement in many compact self-contained "package-type" commercial SMs. (Where gear-trains are used, they must be of "instrument quality," especially when a thousandth of an inch in the position report represents an inch in the position of the output load.) In other SMs—especially the larger and costlier ones—the repeat-back function is accomplished by electrical position-repeating systems, generally of the rotary-inductor type. (These, too, must be of precision quality. During the second world war the Navy paid astonishingly high prices for some of these "synchros.")

In Figs. 7-7 and 7-8, to emphasize where the repeat-back means ends in the error-measuring means and closes the loop, an arrowhead symbol represents a sliding contact and a zigzag symbol represents a simple voltage divider. In actual SMs the physical form of this conjunction may be a precision variable resistor, capacitor, inductor, or any other convenient arrangement for producing an effect (usually a voltage) which is *exactly* related to the cause—the error angle. The relation between error angle and error signal may be simple proportionality, or quadratic, or square root, or a trigonometric relation, or a time function such as integral or

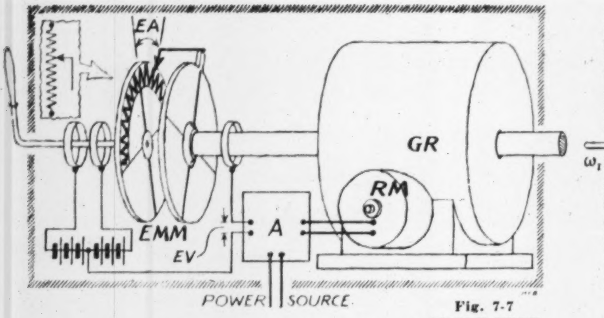


Fig. 7-7
ANGLE TYPE

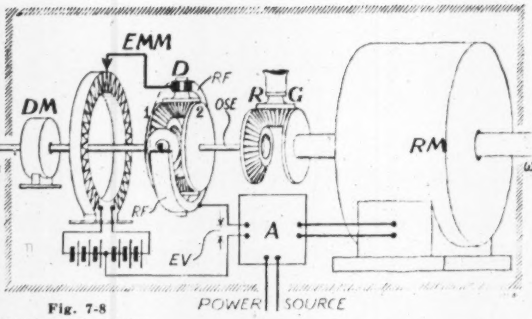


Fig. 7-8
VELOCITY TYPE

A—Amplifier.
D—Differential gearing whose ring-frame remains stationary in absence of error.
DM—Damping means.
EA—Error angle.
EMM—Error measuring means.
EV—Error voltage.
GR—Gear-reducer unit.
OSE—Output shaft extension.
RF—Ring frame or "spider."
RG—Reversing gear.
RM—Reversing motor.

derivative—to suit the requirements of the "brain-box" *A*.

In Figs. 7-7 and 7-8 the repeat-back member, as a member of the error-measuring means *EMM*, generates an error voltage *EV* which is linearly proportional to the error angle *EA;* and the polarity of *EV* corresponds to the sign of *EA*. The center-tapped battery of six cells is an actual physical component of a few SMs; in most SMs powered by a commercial a-c. supply, step-down transformers and rectifiers are used and the design is such as to assure that $EV=0$ when $EA=0$.

(At this point it is well to note that this conversion of an error angle into an error voltage does not constitute feedback. No portion of the output power or energy is fed back to the input —which input is not a voltage but a position: the position of the input spindle. The SMs shown in Figs. 7-7 and 7-8 may or may not be feedback type SMs. The diagrams do not show any feedback; the possibility of the presence of feedback in either or both will be explained later.)

The battery or its equivalent is a source of auxiliary power. The function of this *EMM* is to enable the input to command this power. Functionally, therefore, this *EMM* could be a prime relay; but it is not, because its output is a voltage, not a wattage. However, the combination of the *EMM* and the amplifier is—again functionally—a relay. The input being theoretically devoid of power, the gain of this relay is infinite. In Fig. 7-1 the relay—whether single-stage or multi-stage—likewise had a theoretically infinite gain.

In Figs. 7-7 and 7-8 the shaded-box symbol signifies that all components of the "chain" between input and output are so shielded from external disturbances that their designed functions *stay put*. We thus differentiate the diagram of a self-contained SM from a process-control diagram where (in general) only the desired value stays put and all else is subject to unforeseen disturbances. The shaded boxes have three "disturbance" openings: (1) for the input, which is random, unlike the desired-value setting of an automatic controller; (2) for the output shaft, which is subject to random changes in friction and other changes, as in the case of a radar antenna in a strong wind; (3) for the power source, which is not always well regulated in industrial applications and is usually subject to voltage and frequency fluctuations in military applications.

In Figs. 7-7 and 7-8 the input is a spindle rotation and the output is a power-shaft rotation, but with the difference that the rotation of the Fig. 7-7 input spindle is limited to 180 degrees whereas that of Fig. 7-8 is unlimited. The first SM is a "plain position" SM (or angular-position SM, or angle-type SM) and therefore a handle has been drawn on its input spindle.

The second is likewise a positioning mechanism (as are all SMs) but it may be called a "speed type" SM because, in order to minimize its error at all times, it must make its output shaft *follow closely* (i.e. "pace") the many-turn rotation of the input spindle whether this input rotation is fast or slow. In other words, in order to start correcting a small load-position error before it grows big, the output *angular velocity* must not be allowed to depart from more than a "short time" (relatively speaking) from the input angular velocity. Therefore, no handle is shown on the input spindle and the Greek-letter symbol for *angular frequency* (speed) is lettered under both the command spindle and the load shaft. (The symbol *J* above the output shaft means *intertance*: the inertia of the load and of the SM's own rotating parts.) In the Fig. 7-8 SM, the *EDM* comprises a differential *D*, which necessitates the use of reversing gear *RG* to make the output shaft extension *OSE* (which drives gear 2) turn in a direction opposite to that of the input spindle (which drives gear 1). Thus the four pinions carried by ring-frame *RF rotate without revolving* when the output shaft angle equals the input-spindle angle (when there is no error). When there is an error angle between input and output, ONE-HALF of this angle is indicated by the ring-frame *RF* and the slider which it carries deviates from the center of the voltage-dividing resistor. The result (assuming a linear resistor) is *EV* proportional to *EA*. Fig. 7-8 shows the slider at the center, indicating zero error.

Note that an *EA* greater than about five radians (286 degrees) cannot be measured and presumably is forbidden. This is a high-precision SM. (In practice, however, a high-precision SM would seldom use the gears shown because they would produce "noise" in the signal-contaminating sense.)

In the angle-type SM, Fig. 7-7, the power unit consists of reversing motor *RM* and gear-reducer *GR*. The motor *RM* should obviously be a relatively small and relatively high-speed one, capable of reversing in a relatively short time. However, the input command is limited to 180 degrees total rotation (as indicated by the angular length of the voltage-dividing resistor on the *EDM*'s input comparison disk), so that a temporary error of 100 percent is permissible. Now then, suppose that instead of a voltage divider —which is a modulating device—there were a simple arrangement of high and low contacts: a polarized Group 6 relay. The action would be on-and-off. But almost the same action would be obtained if the gain of amplifier *A* were maximized: if a "very small" value of *EV* resulted in full amplifier output. In other words, if a small (say a tenth-degree) *EA* resulted in unimpeded flow of electric energy from the power source to *RM*, the action would be practically on-and-off. Thus, referring back to the first footnote in Part 1, it may be added that no sharp boundary divides the on-off-relay SMs from the modulating-relay SMs. In practice, of course, the gain of *A* in the Fig. 7-7 SM would be adjusted to supply full power to *RM* at an *EA* greater than a tenth degree and much less than 180 degrees—certainly less than 90 degrees and probably less than 45 degrees. The optimal adjustment would depend largely on the maximal available output torque, on the speed-torque characteristic of *RM*, on the total inertance of *RM*, *GR* and load, on the amount of "anti-hunt" output damping, and on the form of the relation between *EA* and wattage to *RM:* whether linearly proportional or not. If the voltage divider is linear (so that *EV* is linearly proportional to *EA*), there would be overshooting whether the proportional band be zero (on-off) or 180 degrees; and, after settling down, the load error or droop angle would be proportional to the proportional-band angle (as explained below under "Transient Response").

PART 3—FOR NON-MATHEMATICIAN READERS WHO STUDIED CHAPTER XII, OR WHO HAD ALREADY LEARNED ITS LESSONS FROM EXPERIENCE WITH THE PERFORMANCE OF MEASURING SYSTEMS

INPUT DAMPING

Consider the physical components of a true random continuous-rotation or speed-type SM such as Fig. 7-8. The reversing motor *RM* has been drawn as a direct-drive motor, its rotor shaft being the output shaft. Therefore, even if the load is not inertial but entirely frictional, the inertance of the rotor of a (relatively) heavy duty reversing motor makes it impossible for the output to follow the input instantaneously (or even "rapidly"). One solution consists in the addition of a component which was not needed in the Fig. 7-7 SM, namely the input damping means *DM*. It may be a simple flywheel, or an elaborate viscous damper, or a combination. The most obvious function of this *DM* is to prevent a step input (infinite acceleration) greater than the measuring range of the *EMM* (in this case, about 570 degrees: twice the voltage-divider length because of the differential). More precisely, the function of this *DM* is to prevent any needlessly high positive or negative acceleration of the input-spindle's rotation, that is: (1) any acceleration of the input spindle which is greater than the no-load pick-up of *RM* plus the maximum-torque-command angle; (2) any decrease in the spindle speed which is greater than the braking of *RM* plus the equivalent inverse-braking-time angle. In either case, the input acceleration is needlessly high because it results in a needlessly large error angle.

This dual function of the input-command's damping means may be explained by an analogy in which a *length* represents the error angle:

You are driving up a slight grade in a light car with a 200-hp. engine. In the next lane is a heavily-loaded truck. On the side of your car hangs a 15-rung ladder, with its rungs marked 10-0-5. The truck driver constantly tries to keep the center of his cab window exactly opposite the zero rung. When the error is zero he maintains his speed, whatever this speed may be. When you are slightly ahead, he speeds up slightly; when you are ahead by a length of 10 rungs, he opens wide his engine's throttle. When you are slightly behind, he brakes a little; when you are 5 rungs behind, he applies maximum braking. Consequently, if at any instant you are ahead by more than 10 rungs, or behind by more than 5 rungs, *the excess error-length is needless.* And if you speed ahead or drop behind by a distance of, say, 30 rungs or two ladder lengths, you will lose control. Under these circumstances, your racing car (representing an undamped input command) should be "damped" to prevent its needlessly high acceleration or braking and the resultant needlessly great error-lengths.

So far the analogy is incomplete because the input car and the output truck, being ordinary highway vehicles, have naturally been assumed to traveling forward only. To make the analogy closer to an actual SM, the vehicles may be a pair of double-header subway cars, each having exactly similar operating characteristics in *both* directions; one car the fast "master" and the other car the heavily-loaded "slave."

Since the function of *DM* is to round out "steps" and to smooth out "jiggles" in the command, the need of a *DM* is not absolute but relative. To a heavy-duty SM with a 500-hp. electric motor, a command in the form of a one-cycle-per-second sine wave, with an amplitude of five turns of the output shaft (ten turns peak-to-peak) would be a "fast jiggle" which this SM could not obey; but this same command could be obeyed accurately by an instrument SM with miniature components. You can verify this by twirling a pipe-cleaner between the palms of your hands ten turns one way and ten turns back, at the rate of two alternations per second: imagine the pipe-cleaner to be the output shaft of a tiny SM; and then imagine it to be the rotor of a 500-hp. motor plus a load of the same order.

This relativity influences the selection of SMs. In order to determine the need of a *DM* and its damping properties, the user should know (1) the highest expectable maximum acceleration of the input command (the "peak"), expressed in radians per second per second; (2) the longest expectable duration of this peak. With both these data at hand, the user can apply three criteria:

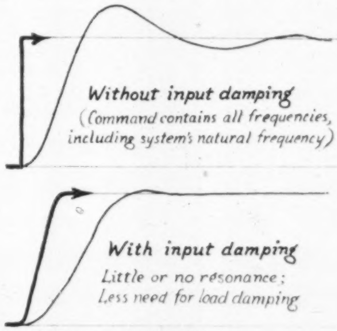


Fig. 7-9

(1) The ratio R_1 of the input acceleration peak to the highest realizable full-load output acceleration of the SM being considered (also expressed in radians per second per second).

(2) The ratio R_2 of the duration (in seconds) of this peak input acceleration to the SM's maximum permissible error angle (in radians). The critical value of this ratio, for $R_1=1$, is 1.41 (from the relation $S = \frac{1}{2} at^2$).

(3) The ratio R_3 of the duration of peak input acceleration to the characteristic time of the SM's power unit plus load. Different authors give different ways of calculating this characteristic time but an approximate value is: Moment of inertia of rotor multiplied by two (because the load usually matches it), divided by damping coefficient of combined SM and load—which in many cases is either the back-emf. damping of an electric motor (obtainable from the manufacturer) or an adjustable artificial damping whose range of values is known. The critical value of R_3 is unity for $R_1=1$.

These three criteria are related to one another. If $R_2 << 1.41$ and $R_3 << 1$, that is to say, if the duration is negligibly small with respect to both the time for *EA* to reach its permissible maximum, and the characteristic time, then R_1 may be greater than unity. If $R_2 > 1.41$ and $R_3 > 1$, then R_1 should $<<1$.

TRANSIENT RESPONSE

There are cases where the foregoing paragraphs will not apply—the input velocity will be expected to increase *relatively* instantaneously. Such a sudden command is called a "step input." The resultant SM behavior, called its transient response, can be computed accurately when the characteristics of all essential components are known. This exact science is highly mathematical. The physical fundamentals, however can be simplified and reduced into the equivalents of those discussed in Ch. XII. They are as follows:

The load (lumped with the rotor) can be imagined to be the mass *M* of Ch. XII. Then if rotation be substituted for translation, the angular displacement *EA* will represent the linear displacement *D*. The equivalent of the spring is provided by the conversion of *EA* into *EV* and the conversion of *EV* by the amplifier into a torque, that is to say a force. If the torque is assumed to be proportional to *EA*, then we have a "spring constant" *K*. The value of *K*, i.e. the "stiffness" of the "spring," will then be the gain of the amplifier. If complete absence of friction and output damping is assumed, the effect of a transient will be sustained oscillation because a transient, in this case, would be equivalent to shutting off the power, rotating the load by hand through *EA* and then suddenly closing the switch. (Obvious result: the load will start rotating, will pass through the zero-error point at highest velocity and will not stop until it reaches *EA* on the opposite side, when the same sequence will begin in reverse, and so on.)

As in Ch. XII the ratio of the "stiffness of the spring" (here the gain) to the mass will determine the natural frequency of the oscillations.

And as in Ch. XII, the amount of damping will determine the dying-down of oscillations.

But now there are important differences, because the SM is a closed-loop system, whose behavior depends less on absolute time intervals between events than on *phase relations*. In other words, the sequence of events is circular and some "causes and effects" are bidirectional, so that the simple equations of Ch. XII cannot be used for plotting response curves. Nevertheless, one of the important differences can be stated in words:

In Ch. XII it was shown that oscillations build up if a *periodic* force is applied (from the outside) to the frame of a mass-spring system, when the frequency of this force equals the natural frequency of the system. In the case of the SM, even though the auxiliary power supply be perfectly steady (regulated d.c., for example) it is possible for a transient to start oscillations

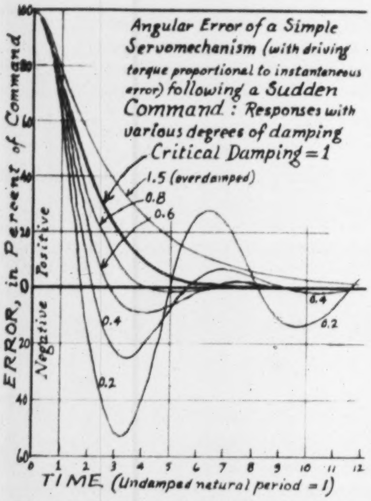


Fig. 7-10. Initially (at time = 0) there is no error. Then, at the moment the measuring-system master issues a sudden command, the error becomes 100 percent—because the load has not yet begun to move. The reader may disregard "positive" and "negative" because these terms are often used in opposite ways. Note from the absence of steady-state load error that (1) the load is constant or (2) this SM happens to be a position SM with output angle proportional to time integral of positional error.

which will build up to a destructive degree; and it is possible to adjust the phase relation between *EA* and instantaneous torque so that the oscillations started by a transient will die down. Analogy: a rocking-chair, which you can ultimately knock over, or gradually stop, by the "timing" of your pushes. (Note: analogy imperfect in two respects: (1) rocking-chair oscillations will not build up; (2) rocking-chair frequency is constant whereas a phase adjustment in the SM will alter the frequency.)

Similarities of Disturbances

If now we assume that the transient is not a sudden command but a sudden load change, the preceding paragraph will still be true. And likewise if the transient is assumed to be a sudden change in the auxiliary-power voltage. To the SM, all three forms of sudden changes are similar.

Hence the three similar "disturbance openings" in the shaded "boxes" of Figs. 7-7 and 7-8. Of course, disturbances occurring *within* these "boxes" are familiar to SM *designers*, for their work consists in improving the components for the benefit of users.

Constant load may produce load error

Actual SMs are often used to position loads which exert a torque on the output shaft even when $EA = 0$. (Familiar example: the stem of an unbalanced control valve.) Therefore let us assume that the load of the SM now under consideration (with output torque proportional to *EA*) is an elevator cage. Let us further assume that this SM is adjusted for passenger comfort: smooth start; no oscillation; smooth stop. Will it completely zero its error? The answer is no and the reason was given above when the output torque was likened to the spring constant. If this SM has been adjusted for five passengers in a ten-passenger cage, it will stop above floor levels when the cage is empty and below floor levels when the cage is full.* The *EA* after settling down will be a fraction of the width of the proportional band. This fraction will be inversely proportional to the "spring stiffness" (amplification) and directly proportional to the positive or negative difference between the design load of passengers and the actual load. This remaining *EA* is the *load error* or *droop.* It cannot be eliminated: if it is minimized by high angular amplification, such as a small pulley on the output shaft (giving a large ratio of *EA* to load-position error) this means either a proportional decrease in elevator speed or a proportional increase in horsepower. According to some authors, a follow-up that suffers from droop is not a true SM.

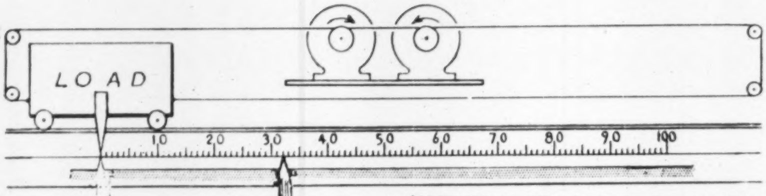


Fig. 7-11

Output Damping

So far, the SM under consideration has been assumed to lack *output* damping. If it were exactly analogous to the systems in Ch. IV, the effect of damping would be exactly the same. Actually, true viscous output damping in most SMs has a closely similar effect in spite of the difference between the closed loop and the open system. The similarity is closest in the case of the transient response, as shown by Fig. 7-10. With critical damping, the error diminishes to about 2 percent of its initial value after an interval of about six times the undamped natural frequency. These curves are those of the response with simple proportionality of instantaneous torque to *EA*. The introduction of damping has slowed down the response. Damping is *power dissipation.* Increasing the gain (the *power* amplification) results in a faster response (higher natural frequency, hence smaller *time* equivalents of the abscissa in Fig. 7-10) but if the damping is not correspondingly increased the effect is to change from a non-oscillatory or slightly underdamped response curve to undesirable oscillations.

Braking, Clutching, etc.

In addition to purely frictional braking, various liquid, gas and electrical systems are used to slow down load oscillations. Rotary-type hydraulic motors have a certain amount of inherent viscous drag which prevents "runaway" speed at no load even with wide-open main throttle. Some electric motors have a type of electromagnetic "viscous" drag (force proportional to speed) adjustable from zero up, by means of a remotely-located knob.

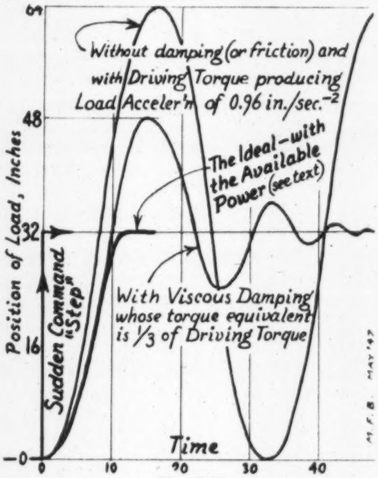


Fig. 7-12

For quick reversal of load movement, two sources of power are sometimes used instead of one reversing motor (whose own inertia would be a parasitic load). Possible arrangements:

(1) With hydraulic or pneumatic power this permits using one cylinder as the driver and the other as the adjustable damper—exchanging their roles at any instant.

(2) With a pair of shafts continuously rotating in opposite directions, as in Fig. 7-11, the quickest reversal of load motion is obtained with a pair of non-slip ratchet-and-pawl clutches—plus shock absorbers, of course. For all but the smallest applications, shock-absorbing clutches are used: hydraulic, magnetic, magnetic-fluid, etc. As a rule, the two clutches are remote-commanded electrically.

"On-and-off" Control

It is important to note that SMs employing any of the schemes just mentioned are not like the ones shown in Figs. 7-7 and 7-8. They do not have the voltage-dividing resistor whereby the torque is proportional to the instantaneous error. Instead, they may be described as the type which has a snap-action 3-position switch whereby a force is instantly applied to the load, driving the load toward the desired new position. See Fig. 7-11.

To simplify the discussion, the force (in either direction) is assumed to be constant—like gravity, so that the simple laws of falling bodies ($s = \frac{1}{2}at^2$, etc.) can be used. Consider first

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*The assumption is an *EMM* as in Fig. 7-8, not the contact strip or vane-type pick-up of the usual automatic elevator.

what happens without damping: when a position-change command is issued, the load starts "falling" toward the desired new point, but without slowing down. The moment it crosses the point, "gravity" ceases to act on it and "antigravity" starts acting on it.

(The time graph, Fig. 7-12, closely resembles a sine curve. It consists of parabolas, each like the trajectory of a projectile in a vacuum.)

Now introduce damping. The "falling body" no longer falls in a vacuum but meets a viscous drag. The result is that the oscillations are attenuated, but (theoretically) never die down.

Obviously, "gravity" should be turned off and "antigravity" turned on *before* the load reaches the commanded new position. In the SM of Fig. 7-11, this means: (1) that the snap-action switch should not be located at the desired new position of the load but somewhere between the initial position and the desired position; (2) that this "somewhere," being a function of known forces, masses, etc., is computable and therefore the correct distance ratio can be built into this type of SM.*

The advantage of this "snap-switch or snap-action valves" type of SM is that it can move a load in the *least* time with a *given amount* of available power. This is in theory; in practice one finds its equivalent on huge machines in shipyards rather than on instrumentation devices.

Therefore let us return to the great majority of SMs (Figs. 7-7 and 7-8); and to the problem of load error or droop.

MODES OF CONTROL

The various solutions of this problem in actual SMs consist, as was briefly mentioned, in replacing the simple instantaneous proportionality of output torque to error by one of a number of more refined relations, involving time functions and phase functions. Two of these are well-known because of their wide use in automatic controllers:

Using the Rate of Change

The "rate" or "derivative" relation causes the amplifier's gain, and hence the instantaneous torque, to be proportional to the rate-of-change of the error. This results in theoretically infinite gain at the start of a transient, when the error must be opposed most strongly, and zero gain when the acceleration of the error (not the error itself) diminishes to zero. Therefore, when it and other adjustments are correct, the effect is to make the transient response of the SM much faster without overshooting; or it is like introducing a non-dissipative form of damping while stepping up the gain. In some circles it is called "boost," "booster," etc.; in others it is called "damping," etc. The correctness of adjustments or settings of actual components depends on their physical characteristics, so that the "ideal" derivative relation cannot be realized in practice. It may be said also that *as a rule* the smaller the SM, the closer the possible approach to the ideal. The fact is that few SMs are ever designed with derivative action only: when derivative is used, it is added to proportional. This combination minimizes droop but does not eliminate it.

Droop Correction

Another output-input time-function relation, likewise familiar to some users of automatic controllers, is termed "integral control" in both SM literature and automatic-control literature. (In the latter it is called "proportional-speed floating," "automatic-reset," "metering control," "variable-speed," and—most vividly descriptive—"droop correction.") As the name "integral" implies, a component of the SM knows at all times the accumulated error—the area between the curve of the transient error and the zero axis—and causes the output torque to be proportional to this area. It can be shown mathematically that an ideal component of this type, aided by ideal characteristics of other components, will at all times cause the *speed* of returning the load to zero to be proportional to the instantaneous error. That is why the terms "integral" and proportional-speed floating" are generally considered to mean the same function. Actually, of course, one seldom finds close approximations of either ideal. It nevertheless is certain that a moderately-good SM with integral control does correct its droop—does minimize its error closer to zero by a factor of 5 to 50 than it would without integral control—and this *result* may be said to be ideal. (Be that as it may, a true SM is defined by some authors as one with the integral mode of zeroing its error.)

In testing for transient response, it often is found convenient (1) to repeat the sudden-command input *automatically*, by means of an instrument or apparatus which produces a square wave—either mechanical (which of course can only approximate a true square wave) or electrical; and (2) to *record* the SM performance by means of a direct-writing or cathode-ray oscillograph. With these facilities, experienced workers can discover, by studying the oscillograms: (1) what imperfections to remedy quickly without mathematical analyses; and (2) how to improve the performance of the SM under test with the barest minimum of computations. This is because transient analysis made tremendous strides during the second world war: it has become an exact science—but its subject-matter is beyond the scope of this Chapter.

PART 4—A PAINLESS GLIMPSE INTO THE TECHNIQUES OF ANALYSIS AND SYNTHESIS OF SERVO SYSTEMS

FREQUENCY-SPECTRUM RESPONSE

This characteristic of any SM is its behavior when the command is a harmonic motion or a sinoidal oscillation of constant amplitude and continually-varying frequency. In the usual tests, this input is not manual but is obtained from a special instrument so that it starts at close to zero frequency and, after the data are recorded (manually or instrumentally), is speeded up in steps until it becomes a "jiggle" too fast for the SM to obey. The test is usually repeated with various amounts of output damping and with various adjustments of whatever components are adjustable.

One need not be an expert to draw valid conclusions from even a glance at the family of curves (example, Fig. 7-13) taken from a simple electromechanical SM—one with the minimum of components, as sketched in Figs. 7-7 and 7-8—when it is subjected to a frequency-response test.

But first a word to explain the universally-accepted Amplitude Ratio or "gain" convention:

It is customary to make the amplitude of the zero-frequency output equal to the amplitude of the zero-frequency command on the graphs, recorder charts, or 'scope screen. Thus, if the command is a 30-degree rotation of a tiny knob (plus and minus 15 deg.) and the output a 10-inch movement (±5 in.) of a gun carriage, both are made one inch (±0.5 in.) or whatever scale is convenient. This permits easy determination of the frequency regions where the "gain" is *smaller* and *larger* than "unity."

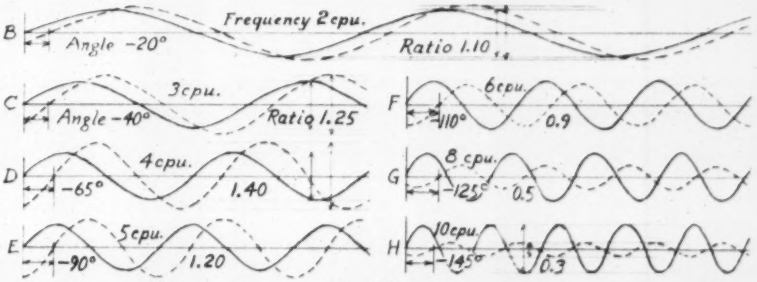

Fig. 7-13

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*For an elementary discussion, including one possible solution by simple arithmetic, see *Instruments*, Vol. 20, Sept. 1947, pages 804-811.

(Then, a plot of these successive ratios as ordinates, with frequencies as abscissa, gives the response discussed a few paragraphs below.)

Fig. 7-13 shows that the imaginary SM under test will not go into wild oscillations because: (1) its greatest amplitude ratio is not excessively high; (2) there is no sharp "peak": the highest-ratio curve is the top of a "mound" with gently-sloping sides.

The sinoid command applied to a speed-type SM (such as Fig. 7-8) for frequency-response tests may be of two distinct kinds:

(1) A command to move the load back and forth (position sinoid). This involves a periodic reversal of direction of rotation—like twirling a pipe-cleaner—with zero speed every half-period. In practice, it is a severe test of mechanical and electrical components, for it brings out the effects of loose play, gear-tooth backlash, starting friction ("stiction"), etc. Even when there are no mechanical imperfections at all inside the "shaded box"—as we are assuming—this test discloses the frequency bands in which the SM is stable and (in some cases) the frequency band in which it will go into wild oscillations.

(2) A speed-variation command without reversing the direction of rotation. In practice, this has advantages, such as obviating the need of distinguishing the effects of loose play, "stiction," etc., from the particular effects being investigated. Its importance will be obvious to anyone who has experienced the rough behavior of an automobile when the driver's foot "floats" loosely on the throttle pedal at low speed: although the car keeps going forward, it feels as if it moved forward and backward violently. This kind of test, on real SMs with less-than-perfect components, enables experts to design SMs that will not "rattle." This kind of test often shows up an unsuspected cause of a serious *dynamic error oscillation* which occurs over a wide frequency region (sometimes at all frequencies) although the guilty component itself may seem to have a harmless sharp narrow peak at an "unused" frequency when taken out of the SM's closed loop and tested for its own resonance.

Instead of applying a sinoid *input command*, i.e. rotating the input spindle, another type of frequency-response test consists in "opening the loop" at a selected point, (for example the *EV* terminals) and introducing at this point an electrical constant-amplitude increasing-frequency sinoid by means of a suitable instrument. Tests of this type yield data on the dynamic characteristics of loop components and on the fits, loose play, etc., *between* components which often cause trouble. As with command tests for over-all characteristics, they are of two kinds: (1) in which the input sinoid causes a periodic reversal of direction; (2) in which the input sinoid causes a periodic change of speed.

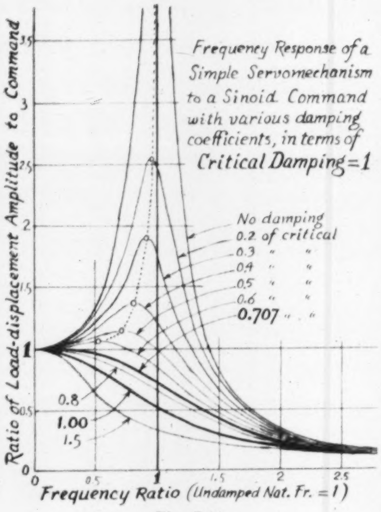

Fig. 7-14

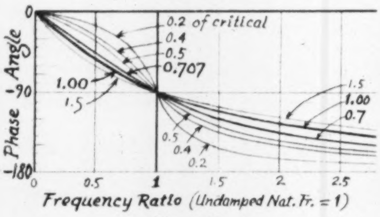

Fig. 7-15

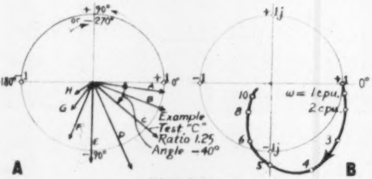

Fig. 7-16

Frequency-spectrum response tests of SMs and of their components yield even more valuable information than can be obtained from oscillographic records of transient response tests. Some of this information is obvious and easily applicable by the average engineer. The most useful items of information, however, can only be extracted from the raw test data by expert use of the latest mathematical techniques. (The geniuses who advanced SM science so rapidly in recent years did so in part by advancing the Queen of the Sciences.) Usually, the raw data of frequency-response tests are two sets of test points easily plotted into two families of curves:

(1) The output-input amplitude ratio (or "magnitude" in electrical parlance) at various frequencies;

(2) The phase angle between output and input at various frequencies.

Figs. 7-14 and 7-15 are the amplitude and phase-angle characteristics of a simple electromechanical SM with various degrees of output damping. They are only the beginning: more families of curves are obtained from other frequency-response tests: (a) of the entire SM with various adjustments or changes other than output damping; (b) of components of the SM. The results of all these tests consist of more families of frequency-response plots—not only like Figs. 7-14 and 7-15 but in the complex plane and various other diagrams originally invented by electrical and radio engineers. From these results, advanced mathematical methods are used to obtain exact data for solving design and application problems many of which had stumped all experts until 1942-1945.

THE NYQUIST CRITERION

One of these new diagrams, which enable designers (makers or *users*) to synthesize SMs for specific applications by assembling the best-fitted commercial components, has recently won well-deserved fame. In itself it is not new, for it was diclosed by Harry Nyquist in January 1932 and by Harold S. Black two years later, as articles in the *Bell Laboratories Record* on how to stabilize electronic amplifiers.

These amplifiers use true feedback: part of the output *power* flows back to the input. The *time* which every pulse of power takes to cause an effect is extremely short, but it is measurable and can be treated as an *angle* in the familiar complex plane of a-c. network engineering. The *phase* of the effect, and of course its magnitude, determine whether it is a good effect or an undesirable one causing instability. In most cases, for stability the open-loop gain must be less than unity when the phase is minus 180 degrees. (This is too brief even for an adequate description.)

Fig. 7-16 does not "explain" the Nyquist plot. It is only a *polar plot* of the sixteen data obtained from the eight tests of Fig. 7-13. The angle of each vector in Fig. A is the lag taken from each curve of Fig. 7-13; its length is the amplitude ratio from the same curve. The ends of the vectors for *all* frequencies form the *locus* shown in Fig. B.

In practice the vector lengths are products of transfer functions; their angles are sums; and the origin is shifted—all according to rigid rules. These can't be dealt with in this discussion, which could only be the brief "painless glimpse" promised in the title.

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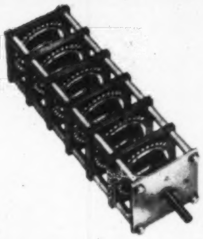

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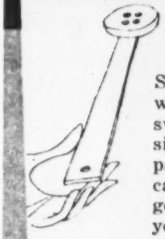

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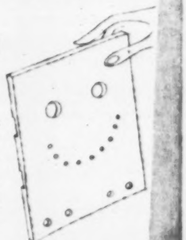

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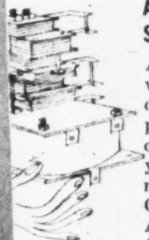

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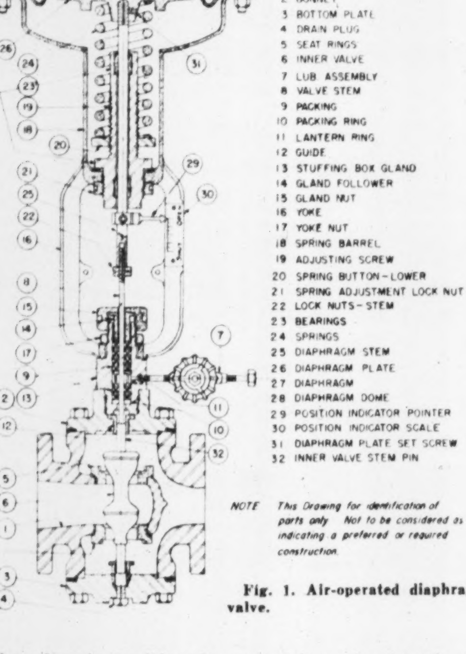
CHAPTER XV

CONTROL VALVES AND THEIR APPLICATIONS

By LYMAN H. ALLEN, JR.

GENERAL

A control valve is a variable restriction in a flow system. It consists of a valve *body* containing an orifice in which a plug, damper, or louver is positioned to vary the opening available for flow. The rate of flow and the pressure drop in the line depend on the position of the plug, or *inner valve*, in the orifice. The plug is positioned in the orifice by a power unit, or *motor*. Thus the three basic parts of a typical control valve are the body, the inner valve, and the motor.


1/4 IPS
1 BODY
2 BONNET
3 BOTTOM PLATE
4 DRAIN PLUG
5 SEAT RINGS
6 INNER VALVE
7 LUB ASSEMBLY
8 VALVE STEM
9 PACKING
10 PACKING RING
11 LANTERN RING
12 GUIDE
13 STUFFING BOX GLAND
14 GLAND FOLLOWER
15 GLAND NUT
16 YOKE
17 YOKE NUT
18 SPRING BARREL
19 ADJUSTING SCREW
20 SPRING BUTTON - LOWER
21 SPRING ADJUSTMENT LOCK NUT
22 LOCK NUTS - STEM
23 BEARINGS
24 SPRINGS
25 DIAPHRAGM STEM
26 DIAPHRAGM PLATE
27 DIAPHRAGM
28 DIAPHRAGM DOME
29 POSITION INDICATOR POINTER
30 POSITION INDICATOR SCALE
31 DIAPHRAGM PLATE SET SCREW
32 INNER VALVE STEM PIN

NOTE This Drawing for identification of parts only Not to be considered as indicating a preferred or required construction.

Fig. 1. Air-operated diaphragm-motor control valve.

The motor usually is driven by some controlling device, or *controller*. The motor can be an electric solenoid, an electric motor, a pneumatic or hydraulic diaphragm, or a pneumatic or hydraulic cylinder. The choice of motor depends on the application.

The inner valve is positioned by the motor in response to demands from the controller. However, three factors prevent the valve from operating perfectly—that is, from having the plug follow the demands of the controller exactly. These three factors are (1) hysteresis and lag in the motor, (2) friction, and (3) static and dynamic unbalance across the valve. Motor lag and hysteresis in an air-operated diaphragm-motor control valve are caused by the resistance of the diaphragm material, or by inertia of the spring. Friction can occur in the valve and motor-stem guides, or in the packing box.

The three factors that prevent the valve from operating perfectly can cause hunting, or cycling, of the process being controlled by the valve. However, the most serious difficulties in control-valve applications usually are due to improper application—that is, the use of an improper valve for the job at hand.

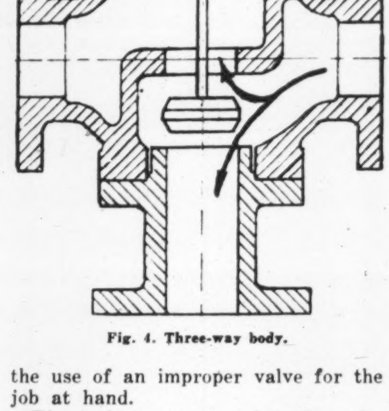


Fig. 4. Three-way body.

Fig. 1 shows a crossection of an air-operated diaphragm-motor control valve, which is the most common type of control valve.

VALVE BODY

Body forms.—The valve body consists of the outside housing, a valve seat or port, and the stuffing box. It contains the valve plug, or inner valve, which moves over the valve seat or port. Typical body forms are shown in Figs. 2, 3, 4, 5, 6, and 7. Fig. 2 shows a *two-way* body, which is commonly used with manual control. It is sometimes called a *globe-style* body with single-bonnet mouth, or a screw-down valve. Fig. 3 shows an *angle* body. Fig. 4 shows a *three-way* body, which is used for mixing or diverting service in on-off or throttling control. The body and inner valve shown in Fig. 4 is also called an unbalanced single-seat disk-type valve. Fig. 5 shows

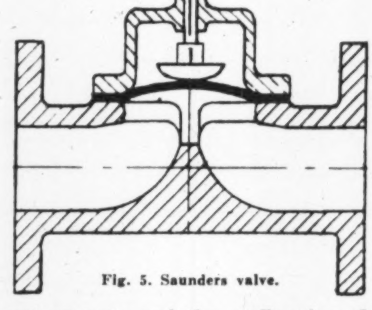


Fig. 5. Saunders valve.

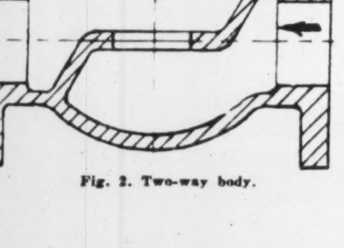


Fig. 2. Two-way body.

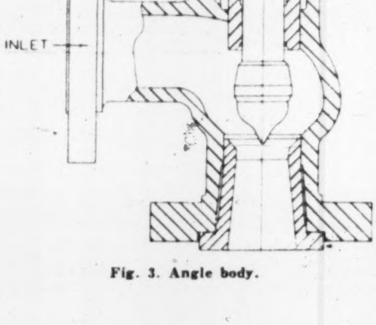


Fig. 3. Angle body.

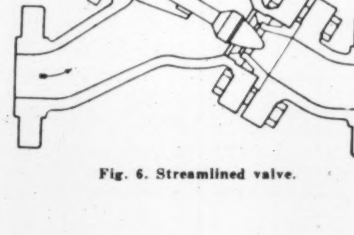


Fig. 6. Streamlined valve.

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the *Saunders-patent-style* body with internal diaphragm, which is used for on-off or limited throttling control of chemicals or fluids carrying solids. Fig. 6 shows a *streamlined split-body "S"* valve, which is used mostly for on-off or throttling control where velocities are high or where the fluids carry abrasive solids. The streamlined body is also called a *venturi-throat* style body. Fig. 7 shows the *butterfly, damper,* or *louver* body style, full-body type. This type valve is used mostly for throttling control where the pressure drop must be kept low, or where the fluid carries solids.

End connections and body ratings.—All body types are generally available with all sizes of screwed ends up to 2 in., and with flanged ends of 0.75 in. and larger.

The nominal body ratings are shown in the following table:

Body Material	*A.S.A. Rating (pounds)*	*Maximum Temperature (degrees F)*
Cast iron	125 and 250	412
Steel and alloy	150, 300, 600, 900, and 1,500	750 (for steel)
Bronze	150 and 300	500

Face-to-face dimensions.—Face-to-face dimensions of valves manufactured before late 1950 conform to the standards of the individual manufacturer, or to A.S.A. Standard B16.10-1933, titled "Face-to-Face Dimensions of Ferrous Flanged and Welded End Valves." However, due to the Instrument Society of America, some control-valve manufacturers have, at great expense, agreed on universal standards for face-to-face dimensions of globe valves. These dimensions are available from manufacturers' catalogs.

MATERIALS

Body Materials.—Control-valve bodies are available in all cast metals and, in the smaller sizes, from bar stock (through 1 in.) and from forged billets (through 3 in.). Control-valve bodies of nickel, monel, Hastelloy A, B, or C, Durimit 20, and type-316 and -304 stainless steels are generally available. Blind flanges, valve bonnets, and cooling-fin sections are also made of these materials. Body bolts or studs are usually of a high-tensile chrome-molybdenum steel such as A.S.T.M. A193-48T grade B7, using high-tensile heat-treated nuts, A.S.T.M. A294-48 class 2H or 2HB. Bolts and studs of special alloys are also available.

Trim Materials.—The choice of material for the valve-trim or inner-valve parts is determined by the erosion and corrosion conditions in the valve. These conditions depend on the fluid being handled and the pressure and temperature. Stainless-steel type 316 is considered a standard trim material by most valve manufacturers and is recommended for fluid temperatures up to 750 F. and for pressure drops to 150 psi. This material is resistant also to the corrosive action of a wide range of industrial chemicals.

Stellite is often welded onto wearing surfaces of inner-valve parts to give increased resistance to erosion, galling, and wear resulting from extreme pressure-drop and temperature conditions. Special corrosion conditions may be met by using alloys such as nickel, monel, and Hastelloy for valve trim. In situations where widely fluctuating temperatures cause threaded guide-bushings and seat-rings to loosen in the valve body, these parts may be welded in. Where separate seat-rings are not desired, stellite may be applied directly to the seating surfaces integral with the valve body.

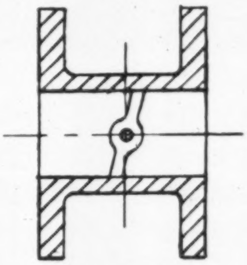


Fig. 7. Butterfly valve.

Valve-trim vs. valve-body materials.—In order to keep cost to a minimum, valve-trim materials which differ widely from body materials are sometimes used. This practice prolongs the life of the accurately machined valve-trim parts, where close tolerances are essential. However, the trim materials must be compatible with the body materials. If they are not, galvanic corrosion of either the body or the trim results.

The galvanic series of the common metals and their alloys, which are located in Physical-Data Handbooks, is the guide in selecting trim materials which are compatible with body materials. When two metals from this list are used together under corrosive conditions, corrosion of the metal listed nearest the top of the list results, and the degree of corrosion depends directly on the distance between the two metals as they appear in the list.

INNER VALVES

The most widely used body design is the globe valve, which is available in either single- or double-seated design. In the double-seated type, the inlet pressure comes in between the two seats and, as the upper seat is only about ⅛ in. larger in diameter than the lower seat, the valve is almost fully balanced. When the valve is balanced, variations in inlet pressure do not affect or change the inner-valve position. However, the double-seated valve should not be used where tight shut-off is desired because temperature variations create unequal expansion between the inner-valve parts and the body, thus making it impossible for both upper and lower parts to be closed at the same time. Leakage flow in the closed position normally does not exceed 2 percent of the maximum flow capacity.

If tight shut-off is required, the single-seated valve must be used. However, the effect of static unbalance must be taken into consideration when selecting the valve operator. Usually the single-seated valve may be used under normal operating conditions in sizes up to 2 in. If larger sizes are used against high pressure drops, and if the valve operator has insufficient power, the valve must be internal pilot operated through the use of a balancing piston.

Inner valves can be classified according to the type of control action—that is, either air to open or air to close.

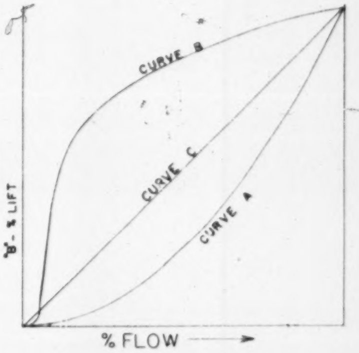


Fig. 8. Flow characteristics.

Inner valves may be classified also according to the type of guiding used—that is, as skirt or wing guided, or as top and bottom guided. The skirt- or wing-guided type is the most economical and is usually satisfactory for pressure drops up to about 100 pounds. For higher pressure drops the top-and-bottom guided inner valve is superior because the close clearances required to prevent vibration of the inner valve can be maintained in the top-and-bottom guided valve.

Flow characteristics.—The shape or contour of the inner valve determines the flow characteristics of the control valve. Until recently the most widely used type of inner valve was one with a *logarithmic-characteristic.* This characteristic results from a valve in which equal increments of stem motion produce equal percentage changes in flow. In recent years, however, design engineers have shown that a *linear characteristic*—that is, one with a linear relation between valve lift and flow rate—is superior in many applications. The inner-valve characteristic is now an important factor in the analysis and design of automatic-control systems.

Various papers by J. G. Ziegler and N. B. Nichols, S. D. Ross, and J. A. Pellettere have shown that an inner valve with a linear characteristic should be used when (1) the fluid flowing through the valve carries solid particles or deposits scale, (2) the major undesired change in the process does not alter the flow rate through the valve at a given valve opening, and the automatic-controller scale is linear, (3) the ratio of maximum to minimum load is greater than eight to one, (4) the valve lag causes most of the effective process lag, or (5) the controller is a linear-scale controller.

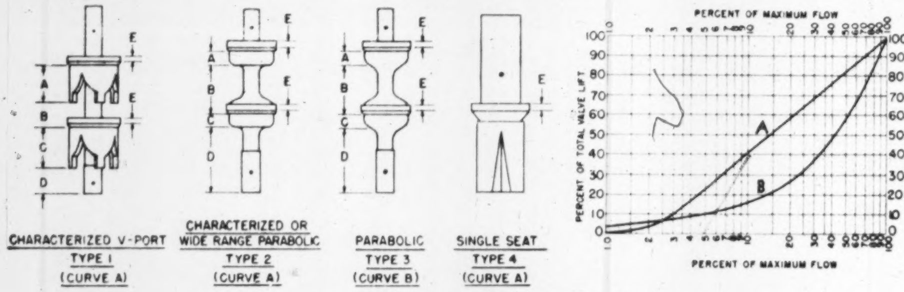


Fig. 9. Inner-valve types and flow characteristics.

An equal-percentage, or logarithmic-characteristic, inner valve should be used when (1) the major undesired load change in the process alters the flow rate through the control valve at a given opening (except when fluid flow is controlled by a linear-scale controller), or (2) most of the pressure drop at maximum flow in the system under control is absorbed by the system itself.

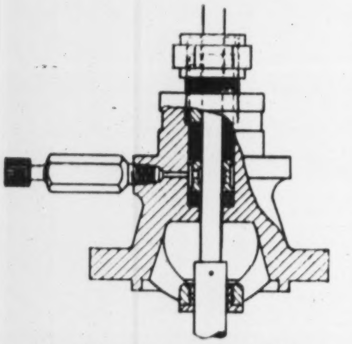
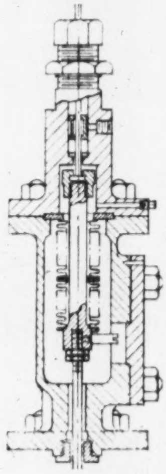


Fig. 10. Formed-ring packing box.

The control-valve characteristic is not important when (1) the proportional band setting of the controller is narrow, as for temperature control of large liquid volumes, and for control of many level and pressure applications, (2) the process has short lags, as for most pressure, flow, and level applications, and for temperature applications where two streams at different temperatures are mixed.

The ideal inner-valve characteristic for any process-control application is that characteristic which, when added to the response-characteristic of the controller, gives a straight line with a slope of 45 degrees. For example, consider the flow-control problem shown in Fig. 8. Curve A in Fig. 8 is the square-root response of the controller pen to changes in flow rate across a control valve of fixed opening when the pressure drop across the valve is varied from maximum to minimum. Curve B is the logarithmic characteristic of an equal-percentage valve. Curve C is the sum of curves A and B (to a different scale, of course). As the sum of the two response curves is a line at an angle of approximately 45 degrees, the equal-percentage valve is the best type of valve for the application.

Fig. 9 shows a few of the many types of inner valves that are available. Curve A is the response characteristic of equal-percentage valves. It is linear in Fig. 9 because it is plotted on semilog paper. Curve B, which is the response characteristic of a linear-characteristic valve, becomes curved when plotted on semilog paper. The characterized V-port, the characterized-parabolic, and the single-seated inner valves are shaped to produce the logarithmic characteristic. The parabolic inner valve produces a linear characteristic.



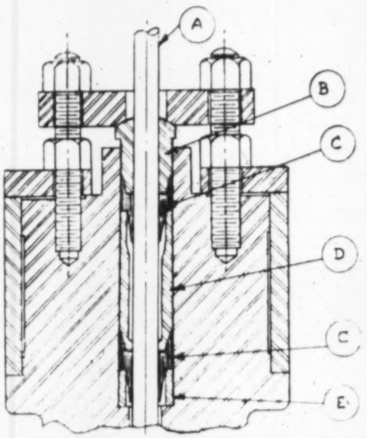


Fig. 11. Bellows-sealed packing box (left).
Fig. 12. Dahl pressure-type seal (above).

Packing Box

The valve packing box, which is also called the stuffing box or gland seal, is the source of most difficulties in valve operation and maintenance. The purpose of the packing box is to seal the fluid in the valve and also to allow the stem to move through the required distance with the least possible friction.

There are three principle types of packing boxes—formed packing ring, bellows sealed, and pressure-type.

The *formed packing ring* packing box, which is shown in Fig. 10, is similar to the hand-valve packing box. Preformed rings or braided-rope packing is used together with a grease lubricant. The name lubricant is misleading. The purpose of the grease is to form the seal. In forming the seal, the grease produces additional friction on the moving stem. The fluid pressure compresses the formed packing, which increases the stem friction further. The stem friction is proportional to the fluid pressure. When the pressure is thousands of pounds per square inch, the friction makes it very difficult to move the stem.

Valve manufacturers usually recommend the proper type of packing and lubricant. The formed rings are made of long-fibre asbestos with graphite impregnation and a binder. The grease is a soap grease compounded for the service. Wide use is made of Silicone grease, which is stable, inert (with few exceptions), and long lasting.

The *bellows-sealed* packing box, which is shown in Fig. 11, uses a stainless-steel bellows instead of packing to seal the fluid in the valve. The bellows-sealed unit consists of a special valve bonnet containing a thin-wall stainless-steel bellows, the upper end of which is welded to the seal-extension stem. The lower end of the bellows is welded to a stainless-steel ring, which is clamped between the body flange and bonnet when the bellows-seal unit is assembled on the valve. Damage to the bellows from torsional twisting is prevented by guiding of the stem extension. A conventional packing gland above the seal provides emergency protection against rupture of the bellows. Travel stops are generally provided. Stuffing-box friction is reduced by the use of the bellows-sealed stuffing box, but increased power in the valve operator is required to overcome the increase in unbalance caused by the cross-sectional area of the bellows. The bellows-seal unit is available for pressures up to 500 psig. at 750 F.

Pressure-type seals are made in different ways by different manufacturers. Usually they are made of Teflon, Kel-f, or other low surface-friction plastic. The Dahl-Patent pressure-type seal, which is shown in Fig. 12, uses a specially shaped Teflon member, or gland seal, which provides a frictionless leak-proof seal on the stem of the control valve. In Fig. 12, component A is a superfinished stem, component B is a gland follower, component C is the Dahl seat, component D is a gland, and component E is a lower gland.

An advantage of a pressure-type seal is that it requires no periodic adjustment or lubrication. Pressure-type seals have been field tested to 8500 psig. for more than two years of continuous service without failure. Satisfactory tests at 22,000 psig. have been made for short periods.

RADIATION BONNET

A conventional type of radiation bonnet is shown in Fig. 13. The bonnet radiates heat to the atmosphere and thus keeps the packing gland and packing material at a safe operating temperature. Radiation bonnets are used usually where the fluid temperature exceeds 450 F. They are used also at temperatures below 32 F. to keep the gland from becoming too cold.

VALVE MOTOR

The valve motor, or valve operator, positions the inner valve in the valve body. The motor can be electric, hydraulic, or pneumatic, depending on the application. The most common type of motor used with automatic throttling control valves is the pneumatically operated diaphragm motor. Its advantages are simplicity and low installation and operating costs.

The most common type of diaphragm motor is the air-loaded spring-return type, such as in Fig. 1. An increase in air pressure moves the operator stem and compresses the spring. When the stem is at rest the forces exerted are in equilibrium—that is, the force of the air-loading pressure on the diaphragm area is equal and opposite to the compression of the spring and the inevitable static friction. When the air-loading pressure is reduced, the spring moves the stem to a new equilibrium position.

The amount of force required to move the stem a small distance is very small. Consider a valve with a stem travel of 1 inch, a diaphragm with an effective area of 100 square inches, and a loading-pressure range of 3 to 15 psig. At the maximum loading of 15 psig. the force exerted on the diaphragm is 15×100, or 1500, pounds. At the minimum loading of 3 psig. the force is 3×100, or 300, pounds. Thus the spring rate required is 1500 minus 300, or 1200, pounds per inch; and a change of 1.2 pounds of force causes a motion of 0.001 inch (neglecting static friction forces). Note that a force of 1.2 pounds is produced by a change in air-loading pressure of only 0.012 psig., or 0.33 inch water. If a diaphragm with an average effective area of 200 square inches were used for 1-inch stem travel, the spring rate would be 12× 200, or 2400, pounds per inch. An increment of motion of 0.001 inch would then require 2.4 pounds of force, which is produced by a pressure change of 2.4/200, or 0.012 psig. Note that a change in pressure of 0.012 psig. produces a motion of 0.001 inch both for the diaphragm with the effective area of 100 square inches and for the diaphragm with the area of 200 square inches.

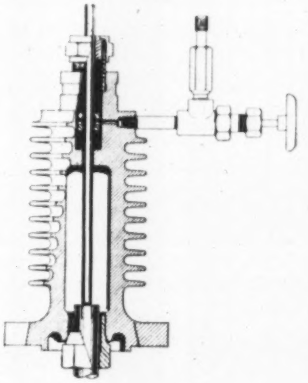


Fig. 13. Radiation bonnet.

The motion of the valve stem is not linear for uniform changes in air loading. This nonlinearity is produced by (1) the rubber in the diaphragm, (2) the variation in spring rate, (3) the number of moving pieces, and (4) the variation in packing-box friction. The rubber not only deflects with air-loading pressure but also stretches. The spring rate varies with deflection because the geometrical shape of the spring changes. For example, as the spring is compressed the mean diameter of the spring increases, and the deflection of the spring varies as the cube of the mean diameter. The number of pieces which move in contact with each other increase the differential gap, or neutral zone, commonly called "flat spot." Packing-box friction is a function of (1) the fluid pressure in the valve, (2) the amount of compression on the packing, and (3) the type of packing. This static friction can be from 5 to more than 100 pounds. When static friction is 100 pounds, it takes a change in air loading of 1 psig. on a diaphragm with an area of 100 square inches to overcome the friction.

Sliding friction is always less than static friction. In operation, the fluid pressure in the valve usually is unsteady. For example, the pressure variations may come from the discharge of a centrifugal pump. The pressure pulsations set up vibrations which continually cause small motions of the stem. These vibrations are helpful in preventing the valve from sticking in one position because of static friction.

Hysteresis.—One of the effects of friction and nonlinear diaphragm characteristic is ***hysteresis*** of the motor valve. If the valve lift is plotted against diaphragm pressure as the pressure first is increased and then decreased, it is found that the two curves thus obtained do not coincide, as shown in Fig. 14. Note that the valve can be in two positions at any one pressure. This effect is called hysteresis. The difference in the two positions that the valve can assume at one pressure usually is between 0 and 2 percent of the total travel, with no compression on the packing. With compression on the packing and fluid pressure in the valve, the hysteresis can be as high as 10 percent of the total travel. In control applications with low sensitivity and high proportional band, the hysteresis produces an insensitive zone, or "dead spot", on the controller range. For example, on a temperature controller with a range of 0 to 100 degrees F. and 100 percent proportional band, a hysteresis of 10 percent causes a dead zone of 10 degrees F. in control.

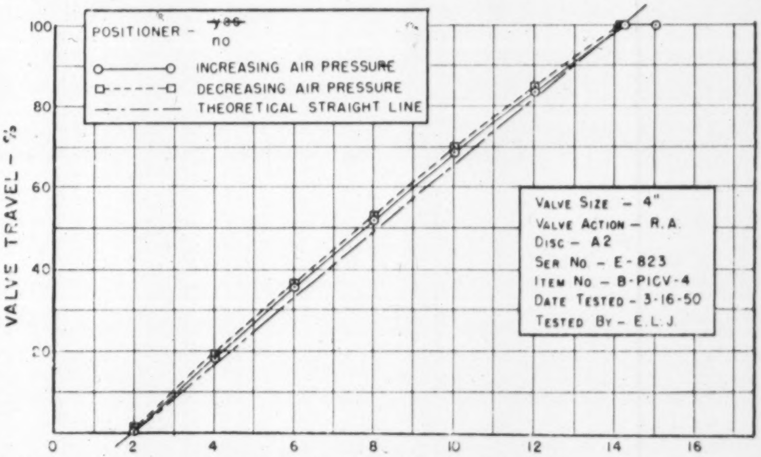


Fig. 14. Valve characteristic showing hysteresis.

VALVE POSITIONER

A valve positioner is a relay-type mechanism that applies power to the valve in response to signals from the controller. The command signals from the controller are usually below 20 psig. The valve positioner converts these commands into signals of any magnitude, depending only on the pressure of the auxiliary compressed-air supply. The valve positioner is essentially a small automatic controller that serves as a power amplifier.

Typical valve positioners are shown in Figs. 5-23 and 5-24, Chapter I. The commands from the controller cause a bellows to expand and contract, which causes a pilot valve to move in the line between the auxiliary high-pressure air supply and the valve. As the pilot valve moves, more or less of the high-pressure air is applied to the control valve. As the valve positioner can apply any air pressure to the control valve, up to the limit of the supply pressure, the positioner can overcome friction and reduce the dead zone.

Valve positioners are recommended for the following applications:

1. Control applications in which complicated process lags make wide proportional bands necessary.
2. High-pressure service in which tight valve-stem packing is necessary.
3. Control valves handling fluids which are highly viscous, which gum the valve, or which have solids in suspension.
4. Control valves with high pressure drops across the valve.
5. Sequential operation of two or more valves from a single controller where each valve has full travel for a portion of the 3-to-15 psig. output of the controller.

VALVE SIZING

The selection of proper valve size is as important as the design and mechanical features of the valve for satisfactory control and adequate valve life.

Only rarely is pipe line size used to determine valve size. The line size in a particular piping system is generally selected to give a fluid velocity in accordance with good engineering practice, whereas the valve size is based on the quantity of fluid flowing and the pressure-drop conditions which must be met.

Too large a valve causes rapid wear to inner-valve parts because the valve plug necessarily operates close to its seat, thus causing wire drawing or concentrated erosion. Control is also unsatisfactory because only a small portion of the total valve stroke is required to handle the flow range from minimum to maximum demand, and extremely accurate valve positioning is required. Furthermore, as relatively small changes in valve position produce large changes in flow, the control instrument must have wide sensitivity or proportional band setting. This magnifies frictional effects.

As the control valve is an orifice, the laws of fluid mechanics can be applied. From Bernoulli's equation the basic equation for flow is:

$$v = \sqrt{2gh},$$

where

v = velocity of flow in ft. per. sec.

g = acceleration due to gravity = 32.2 ft. per sec.^{2}

h = pressure head in feet of liquid flowing.

Multiply both sides of the equation by the crossectional area of the orifice opening and insert the constant c in the right-hand side to represent the orifice discharge coefficient.

$$vA = Q = cA\sqrt{2gh}$$

where

Q = flow in cubic ft. per sec.

A = area of orifice in square feet.

Then, by converting h into p and by taking the specific gravity (G) into consideration, the equation for *liquid flow* becomes

$$(1) \quad Q_L = C_v\sqrt{(p_1 - p_2)/G}$$

where

Q_L = Gallons of liquid per minute

p_1 = Upstream pressure in pounds per sq. in.

p_2 = Downstream pressure in pounds per sq. in.

G = Specific gravity of fluid (water = 1)

C_v = Valve discharge coefficient based on nominal valve size.

In a similar way the following equation for *steam* flow is

$$(2) \quad Q_S = 63.4C_v\sqrt{(p_1 - p_2)/V}$$

where

Q_S = Pounds steam per hour

V = Specific volume of entering steam

C_v, p_1, p_2 are as in liquid-flow equation (1).

Similarly, the equation for *gas* flow is

$$(3) \quad Q_G = 1364C_v\sqrt{\frac{(p_1 - p_2)P}{(460 + F)G}}$$

where

Q_G = Cubic feet of gas per hour at 60 F. and 14.7 psig.

P = Outlet pressure in pounds per sq. in. absolute.

G = Specific gravity of gas (air = 1)

F = Gas temperature

C_v, p_1, p_2 as in liquid-flow equations.

Note: $(p_1 - p_2)$ for gas or steam should not be greater than $P/2$.

Representative C_v values can be obtained from manufacturers' catalogs. By use of the appropriate flow formula and C_v value, control-valve capacity can be determined if the valve size and all flowing conditions are known.

If the flow rate and flowing conditions are known, the basic flow formulae may be revised into the following forms for calculation of C_v and valve size.

$$(4) \quad C_v = Q_L\sqrt{G/(p_1 - p_2)} \quad \text{(liquid)}$$

$$(5) \quad C_v = 0.0159Q_S\sqrt{V/(p_1 - p_2)} \quad \text{(steam)}$$

$$(6) \quad C_v = 0.000735Q_G\sqrt{\frac{(460 + F)G}{(p_1 - p_2)P}} \quad \text{(gas)}$$

The flowing quantity should be multiplied by correction factors for various plug characteristics to calculate the correct C_v value.

The relationship between percent of maximum valve lift and percent of maximum flow for linear and equal-percentage valve plugs is shown in Fig. 9. The use of this data permits selection of a valve size capable of passing a maximum flow at a certain percent of maximum lift of the valve plug as follows:

a. At the desired percent of maximum lift determine the percent of maximum flow obtained for the particular valve plug used.

b. Divide the desired flow by percent of maximum flow from (a) to obtain maximum flow.

c. From maximum flow (b) calculate C_v and the required valve size.

In gas-flow equations 3 and 6, most manufacturers recommend that the pressure drop, $p_1 - p_2$, be multiplied by the downstream pressure. This gives conservative results and a safety factor. However, use of upstream pressure is recommended by a few valve manufacturers. Use of upstream pressure gives higher values for flow capacities and C_v. The derivation of the flow equations for a compressible ideal fluid flowing through an orifice is based on the change in enthalpy with no change in entropy, which is a function of differential pressure times the upstream pressure. This is why the upstream pressure is used by some manufacturers.

For fluid flow where flashing of the flowing fluid occurs in the valve body, proper valve size can be calculated as follows:

a. Calculate the percent of liquid by weight which vaporizes:

$$x = \frac{S(T_1 - T_2)}{H},$$

where

S = Specific heat of liquid

T_1 = Upstream temperature

T_2 = Downstream temperature

H = Latent heat of vapor at T_2.

b. Calculate quantity of liquid and vapor at downstream conditions.

c. Calculate C_v for quantity of *downstream liquid*.

d. Calculate C_v for quantity of *downstream vapor*.

e. Add values of C_v from (c) and (d)

f. Calculate valve size from total of C_v's calculated by (e).

Some manufacturers produce slide rules which have the C_v's for many types of valves. These values of C_v usually are adequate for calculating valve size for particular process applications.

It is generally not necessary to consider the effect of *viscosity* when sizing a control valve unless the viscosity of the flowing liquid is considerably greater than that of water. In cases where a highly viscous solution is to be handled, the C_v value calculated by equations 4, 5 or 6 should be corrected as follows:

a. Determine the uncorrected C_v through the use of equation 4, 5, or 6.

b. Calculate the viscosity index by the following equation:

$$\text{viscosity index} = 94.8 Q_L / \sqrt{C_v \times \text{Stokes}},$$

where

Q_L = Gallons flow per minute

C_v = Uncorrected C_v

Stokes = Viscosity in poises times specific gravity of fluid

c. Using the viscosity index calculated in b, determine the correction factor K for valve-flow coefficient from Fig. 15.

d. Multiply the uncorrected C_v by correction factor K.

LINE SIZE

In the application of control valves, it is generally desirable to use a pipe line size as large as practical in order to minimize line friction and to make use of the complete rangeability of the valve. It should be borne in mind that all inner-valve characteristic curves are plotted on the assumption that the pressure drop across the valve is a constant. In actual use this is not true. As flow increases, line loss generally increases as the second power of the velocity. Therefore, whereas at low flow rates nearly the total pressure drop in the system occurs across the control valve, at maximum flow this drop is reduced by a line drop which often is a considerable fraction of the total system drop. Therefore, it is obvious that if wide rangeability in a control system is desired, pressure drop due to pipe-line friction should be kept to a minimum. Liquid flow lines should be sized for a velocity not exceeding 10 feet per second.

Another method of sizing a pipe line is to (1) assume that an orifice having a d/D ratio of 0.60 and a drop of 100 inches of water is installed in the line, and (2) then calculate the line size necessary. A third method is to assume a drop of 5 to 6 pounds per square inch through a valve at the desired flow rate and calculate the valve size required, which can be then used for the line size. As a generalization, the pressure drop across a control valve should always be 40 percent or more of the total drop in the fluid system under control. An excellent paper by Otto Kneisel titled "Liquid Flow Characteristics of a Pipe Line and a Control Valve" discusses this subject.

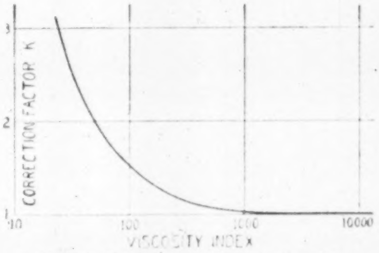


Fig. 15. Correction factor vs. viscosity.

INSTALLATION

Diaphragm control valves are usually installed in a vertical position, but they may be installed in any other position as long as correct direction of flow is maintained.

Valve flanges generally are marked "IN" or "OUT", or a direction-of-flow arrow is cast on each valve body. For single-seat valves it is essential that the flow be in a direction that tends to lift the plug off its seat.

The diaphragm air connection is usually tapped with a ¼-inch national pipe thread.

Before placing a valve in service, check it for full travel to make sure that no dirt or other debris has gotten into the valve during installation.

The valve is shipped without lubrication; before placing the valve in service, lubricate it in accordance with the manufacturer's instructions. Stem packing life is directly dependent on lubrication. Lubricant should be added often enough to keep line fluid, under pressure, from cutting through the stem packing. The frequency of lubrication depends on the service and use of the valve; experience is the best guide for routine lubrication.

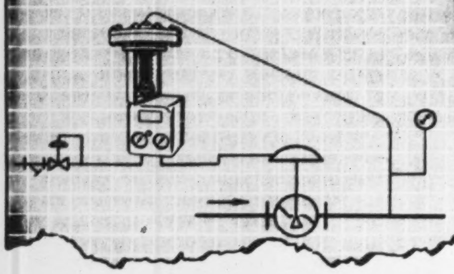
When adding lubricant to valves equipped with isolating valves, open the isolating valves before turning in the lubricator plunger; close the isolating valve after enough lubricant has been fed to the packing gland. Never remove the plunger to insert a new cartridge without first closing the isolating valve.

TROUBLE SHOOTING

The most common trouble in valve operation is in the packing-gland lubrication and adjustment. The valve stem must be kept clean and free of corrosion. The gland-follower flange must be pulled up square and even to prevent cocking of the gland follower. Leakage around the stem is generally a sign of insufficient lubrication. Keep the lubricator clean and free of corrosion. The following steps are recommended for checking a control valve:

1. Check valve action for smooth motion. Too tight an adjustment of the packing causes sticking.
2. Check valve for full stroke for the spring pressure range given on nameplate. Check valve positioner; if used, for proper stroke setting.
3. In a single-seat valve, check direction of fluid flow. A shift in spring range is normal with change in body pressure.
4. If valve does not shut off reasonably tight after a period of operation, the plug and seat may be worn and should be replaced. Check impulse lines from controller for leaks or restrictions in tubing (pneumatic or hydraulic), or for improper or loose electrical connections.

WHEN TO USE A CONTROLLER



PRESSURE, TEMPERATURE AND LIQUID LEVEL CONTROLLERS

Leslie Controllers consist of a single or double seated diaphragm control valve operated by a Control Pilot. The latter is an air, water or oil actuated device that produces a variable loading pressure to the valve diaphragm in response to a pressure, temperature or level change in the controlled medium. Controllers are used for any one or any combination of the following conditions:

★ When an exactly controlled level, pressure or temperature is required.

★ When power is needed to assure automatic valve opening after prolonged, tight shut-off.

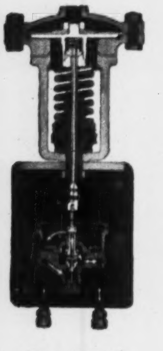
★ When power is needed to operate single-seated valves under high pressure drop.

★ When the available fluid pressure differential doesn't supply enough power for self-operation.

★ When extreme pressure reductions are necessary (i.e. 600 reduced to 10 psi, 900 to 2 psi, 2150 to 5 psi); all can be handled in one step.

★ When fluid contamination requires the simplest type regulating valve for dependable operation.

★ When operation from either a nearby or remote control station is desired.



Control Pilot
Type PD

LESLIE CONTROL PILOTS

Simple mechanical device employing constant supply of clean air, gas, water or light oil at 20-22 psi to produce a variable output or loading pressure of 0-20 psi in response to a level, pressure or temperature change applied to operate a control valve or power cylinder controlling fluid flow.

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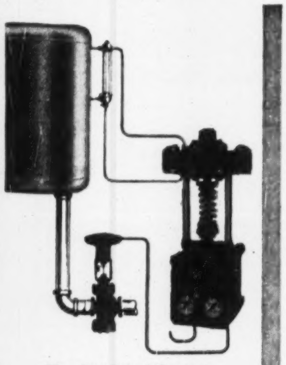

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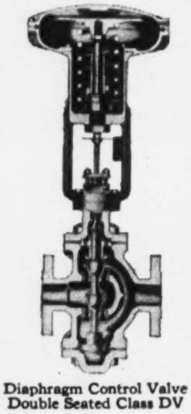

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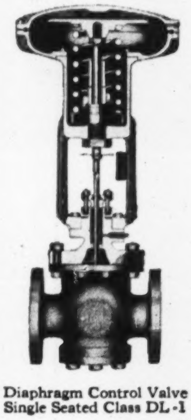

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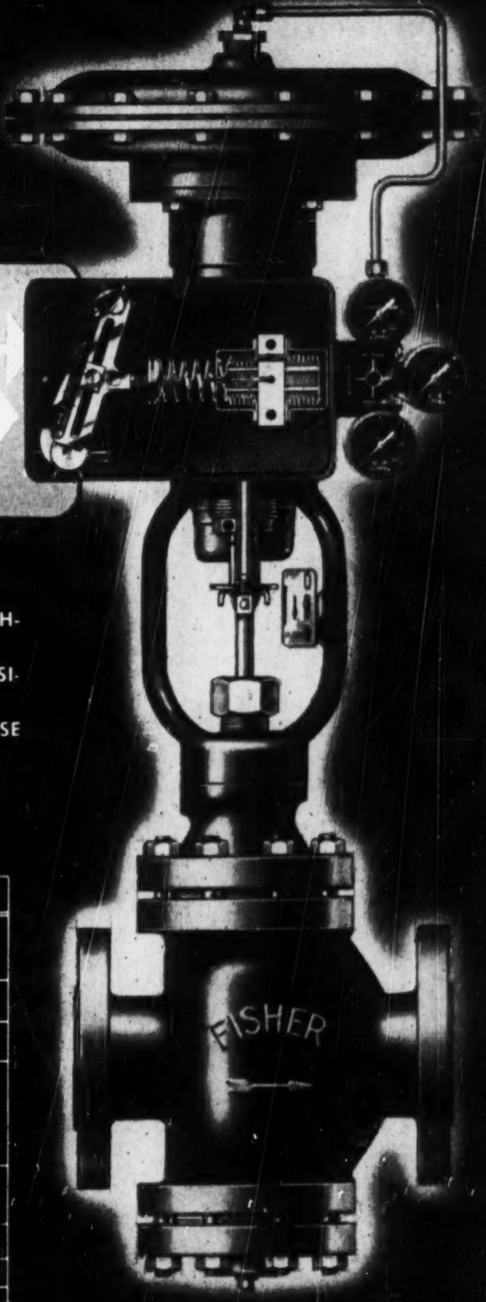

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TEST			FISHER TYPE 3500
INSTRUMENT PRESSURE SENSITIVITY CONTROLLING PRESSURE CHANGE NEEDED TO PRODUCE 2 LBS. TO 15 LBS. TO DIAPHRAGM			0.07 LB
STEM MOVEMENT SENSITIVITY AMOUNT STEM CHANGE TO PRODUCE 2 LBS. TO 15 LBS. TO DIAPHRAGM	½" TRAVEL		0.0037" AVE.
	2" TRAVEL		0.015" AVE.
SPEED TIME IN SECONDS FOR FULL TRAVEL	SIZE	TRAVEL	
	DD	¼"	1.2 — 1.2 SEC.
	FF	1½"	4.2 TO 4.8 SEC.
	GG	2"	7.2 SPC TO 9.6 SEC.
	HH	2"	10.5 TO 12.6 SEC.
LAG ERROR IN POSITION AT 9 LBS. CONTROLLER PRESSURE	½" TRAVEL		0.0006" AVE.
	2" TRAVEL		0.001" AVE.
EFFECT OF VARIATIONS IN AIR SUPPLY PRESSURE	½" TRAVEL		0.1 LB. PER 5 LB. CHANGE
	2" TRAVEL		0.1 LB. PER 5 LB. CHANGE
CHARACTERISTICS CONTROLLED P VS DIAPHRAGM P			LINEAR
COMMENTS			STABLE ADJUSTMENTS ALL EASY AND SIMPLE
AIR CONSUMPTION NORMAL 9 LBS. DIAPHRAGM PRESSURE			15.0 CU FT/HR

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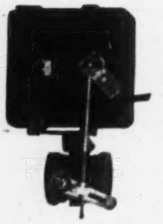

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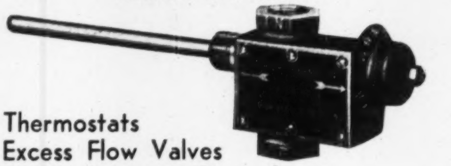

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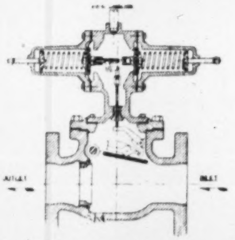

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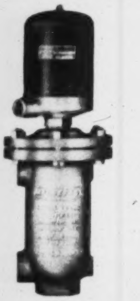

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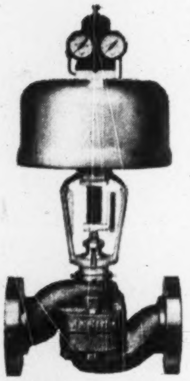

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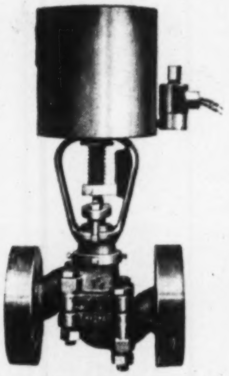

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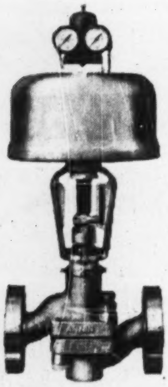

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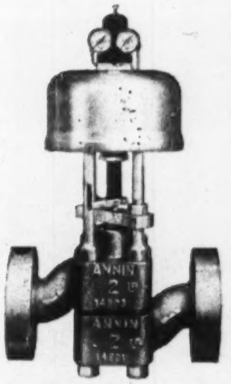

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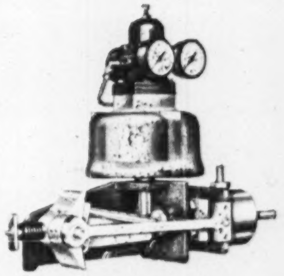

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